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THESIS

ELASTIC-PLASTIC FRACTURE TOUGHNESS TESTING METHODS

by

Wayne Kurt Tritchler

December 1983

Thesis Advisor: K. D. Challenger

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the necessary information to control the testing machine. The program automatically plots the J versus crack extension curve and determines J_{Ic} upon completion of the test. A second program is presented to assist the operator in fatigue precracking the specimen. A third program is used to recall, list and plot the data that were stored on diskette during the test.

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Elastic-Plastic Fracture Toughness Testing Methods

by

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Lieutenant Commander, United States Navy
B.S.E.Sci., Iowa State University, 1975

Subimitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

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I dedicate this work to my wife Barbara and sons, Victor and Michael. While they may not understand this work they have provided the encouragement and support required to complete it.

I. INTRODUCTION

A. GENERAL

The toughness of a material is a measure of the energy per unit volume required to cause fracture. It can be quantified by simply taking the area under the true stress strain curve from a simple tension test [Ref. 1]. The practical usefulness of this measurement is limited however, because it provides no information on the material's ability to resist crack propagation. Since all real structures contain notches or cracks of some sort, by design or otherwise, which act as stress concentrators, another measurement of toughness was developed called fracture toughness.

The fracture toughness (K_c) of a material is a measure of the resistance of the material to fracture in the presence of a defect. K is defined as the plane strain fracture toughness and is used to quantify a material's resistance to crack propagation [Ref. 2]. The American Society for Testing and Materials (ASTM) developed Standard E399-83 [Ref. 3] which establishes precise details for accepted testing procedures. The standard also provides rigid criteria for the specimen size and geometry to ensure plane strain conditions exist at the tip of the crack.

The J-integral method, developed by Rice in 1968, provides a means of including plastic deformation at the crack tip [Ref. 4]. J is a measure of the intensity of the entire elastic-plastic stress-strain field that surrounds the crack tip. J_{Ic} is defined as the value of J at the onset of cracking. J-integral testing has gained acceptance as a valuable means of evaluating a metallic material's resistance to crack initiation as demonstrated by establishment of ASTM Standard E813-81 [Ref. 5]. The measured value of J_{Ic} has practical applications in measuring the effects of metallurgical variables, heat treatments, and weldments and is being used by researchers today to make such quantitative distinctions [Ref. 5-7].

B. J_{Ic} VERSUS K_{Ic} TESTING

The procedures established by ASTM Standard E399-83 for obtaining K_{1c} impose minimum specimen size requirements that cause difficulty when testing materials that possess high toughness. The specimen thickness must be sufficient to cause plane strain conditions to exist [Ref. 3]. Hertzberg [Ref. 2] presents the empirical equation developed by Brown and Srawley [Ref. 8]:

$$t \text{ and } a > 2.5 * (K_{Ic}/Ys)$$

where

t = specimen thickness

a = crack length

K_{Ic} = plane strain fracture toughness

Ys = yield strength

A similar analysis for J-integral test specimens reveals that:

$$b \text{ or } B > 25 * (J_{Ic}/Fs)$$

where

b = initial uncracked ligament

B = specimen thickness

J_{Ic} = anticipated value if J_{Ic}
recheck when test is completed

Fs = flow stress [(Ys+Uts)/2]

Hertzberg takes this result one step further by showing that J_{Ic} equals $(K_{Ic})^2/E$ (where E equals the material's elastic modulus) for J_{Ic}. By dividing the two equations one sees that:

$$(K_{Ic} \text{ specimen size}) > 20 * (J_{Ic} \text{ specimen size})$$

thus, because the J-integral allows plastic deformation, one of its most significant advantages is that a satisfactory specimen can be obtained at one-twentieth (1/20) of the thickness of a K_{Ic} specimen. This not only means smaller specimens may be used but, also, smaller testing machines are required and therefore costs are reduced. [Ref. 2]

Although J_{Ic} and K_{Ic} provide a different measure of toughness, J_{Ic} can be used to estimate K_{Ic}. ASTM Standard

E813-81 [Ref. 5] provides limited guidelines on the relationship between the two.

C. PURPOSE AND SCOPE OF RESEARCH

The purpose of this thesis is to develop the procedures required to obtain J_{Ic} from J-integral test results using equipment currently available within the Materials Science group of the Mechanical Engineering Department at the Naval Postgraduate School (NPS). A list of the major equipment follows:

a. Series 810 MTS machine
b. HP-9826 computer with internal disk drive and 320K random access memory
c. HP-3497A data acquisition system
d. HP-3437A voltmeter
e. HP-2671G thermal printer
f. HP-7225B graphics plotter

Figure 1 shows the system layout.

The test method developed is to comply with ASTM Standard E813-81 [Ref. 5], be easy for others to use, and require a minimum of operator interaction. It is specifically designed for use with three point bend specimens using a single vice multiple specimen approach. The method developed and presented here covers the entire test, including specimen preparation, precracking, testing, and validation of results.

II. NATURE OF THE PROBLEM

A. J-INTEGRAL

The J-integral is a mathematical expression used to characterize the near tip stress-strain environment of cracked elastic-plastic bodies [Ref. 9]. It is a path independent line integral that surrounds the crack tip for non-linear plastic metallic materials [Ref.5]. The equation delveloped by Rice is [Ref. 4]:

$$J = \int_{\Gamma} (W\,dy - T\cdot(\partial u/\partial x)\,ds)$$

where

W = loading work per unit volume, or for elastic bodies, strain energy

Γ = the path of the integral, which encloses the crack tip

ds = increment of the contour path

T = outward traction vector on ds

u = displacement vector at ds

x,y,z = rectangular coordinates

$T\cdot(\partial u/\partial x)ds$ = the rate of work input from the stress field into the area enclosed by Γ.

Figure 2 provides a pictorial representation of this equation.

The mathematical expression developed by Rice [Ref. 4] has been manipulated and reduced to simpler forms for

specific specimen geometries. Rice, Paris, and Merkel [Ref. 10] reduced the J-integral expression for a three point bend specimen to:

$$J = \frac{2 * A}{b * B}$$

where

J = resistance to crack initiation

A = area under load versus load line displacement curve

b = uncracked ligament

B = specimen thickness

This thesis is not intended to redevelop the J-integral but rather apply it, therefore only the result is presented here.

More recent work by Ernst, Paris, and Landes [Ref. 11] corrects the calculation of J due to crack growth by means of the following equation:

$$J_{(i+1)} = (J_i + (n/b)_i * A_{i,i+1}) * (1-(Y/b)*(a_{i+1}-a_i))$$

where

$J_{(i+1)}$ = current value of J

J_i = last J computed

n = 1 for three point bend type specimens

$A_{i,i+1}$ = area enclosed by the actual test record and lines of constant displacement d_i and d_{i+1}

Y = 1 for three point bend type specimens

b = current uncracked ligament

W = specimen width

a_i = last crack length

a_{i+1} = current crack length

Correcting for crack growth during the test is necessary when using a single specimen approach as used by this method.

The blunting line defined as:

$$J = 2 * Fs * delta\_a$$

where

Fs = flow stress

delta_ a = change in crack length

approximates apparent crack advance due to crack tip blunting in the absence of slow-stable crack tearing. It is plotted on the J versus crack extension plot. A linear regression fit through the applicable data points is then plotted. The intersection of the two lines is by definition J_{Ic} (see Figure 3).[Ref. 5]

B. PREVIOUS WORK

The early experimental methods used to obtain J_{Ic} required the preparation of several specimens. Each specimen received a different load. The specimens were then heat tinted (to identify crack length) and broken apart. Each specimen provided one data point on the J versus crack extension curve, commonly referred to as the J-R curve [Ref.

9 and 11]. Checks were then performed on the validity of the data. A minimum of four valid data points were required to obtain a linear least squares fit and hence J_{Ic} [Ref. 5,10 and 12].

Researchers over the last five years have developed a much improved test method whereby a single specimen can be used. Today's computerized data acquisition equipment and data manipulation are ideally suited for the task. By relating the compliance (how much a specimen bends under a given load) to the crack length, all the data required to obtain the J-R curve can be collected by using a single specimen [Ref.11-16]. Clarke [Ref.16] states that prior to the use of computers the time required for data reduction to obtain the J-R curve was four to five hours. Using computerized, single specimen, unloading compliance methods it is now possible to to obtain the J-R curve in a matter of twenty to thirty minutes after the test starts. The obvious savings in specimen preparation and data reduction have made the J-integral a valuable means of analysis where no practical means previously existed.

C. TEST CRITERIA

The test method developed in this thesis is specifically designed for use on a three point bend specimen. It utilizes the single specimen approach by relating the crack opening displacement (COD) compliance to the crack length.

The following equations are currently used by DTNSRDC. For bend specimens with a span to width (S/W) ratio of 4.0, Dr. J. Joyce [Ref. 17] of the United States Naval Academy determined:

$$a/W = 0.998265 - 3.81662 * U - 1.80596 * U^2 + 32.31038 * U^3 - 44.15665 * U^4 - 52.67876 * U^5$$

where

a = crack length

W = specimen width

$$U = \frac{1}{\left(\frac{4 * B_e * E * W * compl}{S}\right)^{1/2} + 1}$$

where

B_e = effective thickness = Bmax - (Bmax - Bmin)^2/Bmax

E = material's elastic modulus

S = span between supports

W = specimen width

compl = compliance = 1/slope of the load versus COD line for the specific unloading.

The reason for using the single specimen approach has already been presented. The reasons a bend type specimen and COD type unloading compliance are used are:

a. Three point bend specimen geometry is better suited than compact tension specimens for testing weldments.

b. Three point bend specimen geometry is also easier to machine than compact-tension specimens.

c. COD voltage readings are less susceptible to noise than linear variable differential transformer (LVDT) voltages used to measure load line displacement.

d. The COD compliance equation affords 0.1% fitting accuracy and allows comparison of results with DTNSRDC test data [Ref. 17].

III. TEST METHOD

A. OVERVIEW

A J-integral test can be divided into three distinct steps, 1) pre-test, 2) test, and 3) post-test. Each of these are described in greater detail in this chapter and presented as a step by step procedure in Appendix A.

After the specimen is machined it must be precracked using cyclic fatigue loading to minimize residual stresses and create a sharp crack tip [Ref. 5]. A computer program was developed to assist the operator in accomplishing this. The program computes the loading parameters for precracking in accordance with ASTM Standards E399-83 and ASTM E813-81 [Ref. 3 and 5]. The operator uses this information to run the MTS machine.

During the J-integral test a second computer program collects and records the load, COD, and load point displacement (deflection). These data are used by the program to determine J and the amount of crack extension for each operator controlled unloading cycle. An unload cycle consists of decreasing the load by 10% of the expected maximum load and reloading to the original load point. The program provides the operator with a real-time graphical representation of the any two parameters (load versus COD or deflection) during the test. It will also plot the J-R

curve and compute J_{Ic} upon completion of taking all the test data. Data are stored on diskette to serve as a record and allow future recall listing or plotting.

The post-test process includes heat tinting the specimen to aid in visual verification of crack extension upon completion of the test as required by ASTM Standard E813-81 [Ref. 5].

B. SPECIMEN PREPARATION

Figure 4 shows specifically the dimensions used in preparing eight specimens from two different one inch thick welded plates of HY-80. One plate was preheated while the other was not. It was necessary to reduce the width to approximately 0.95 inches to remove the distortion (bow) created by the weld. Four specimens were prepared from each plate, the machined notch was placed in the weld metal for two and in the base metal for the other two. The clip gage (used to measure COD) is attached to the top of the specimen by means of two cut razor blades. The blades are held down by small straps which allow adjustment of the initial gap. The initial gap is set to 0.475 inches, the calibrated zero setting for the clip gage, by means of a machined gage tool that rests in the specimen's machined notch. This method is also used by DTNSRDC.

Two additional holes are drilled and tapped for retaining a small bracket on the face of the specimen. The

bracket is used to provide a sensing point for a linear variable differential transformer (LVDT). The LVDT signal is used to calculate the area under the load versus displacement curve. At present the external LVDT is unable to control the MTS machine so the current method uses the MTS' internal LVDT to measure deflection via actuator movement.

Clarke [Ref. 16] states that side grooves improve the accuracy of calculating the crack length when using unloading compliance procedures. The side grooves reduce plastic deformation on the surface and aid in propagating a straighter crack front. DTNSRDC has found 20% side grooving produces the best results, hence the same was used for this work.

After the specimen is prepared a test record sheet (see Appendix B) is completed. Notch and side groove depths can be measured using a dial indicator with a needle tip. The record provides the operator with ready access to the information necessary to run the precracking and test programs.

C. PRECRACKING

Before the J-integral test can be performed the specimen must be precracked to establish a sharp crack tip. ASTM Standards E813-81 and E399-83 establish parameters that must be met during precracking to prevent over-stressing the

specimen or propagating the crack through the entire width. Precracking is accomplished with the aid of a program called "PRECRACK" which will compute loading requirements based upon these paramenters.

The program, written in HP-Basic, affords flexibilty by allowing the use of different bend specimen sizes and materials. It is easy to use due to its interactive design and easy to modify should such a need arise. A listing of "PRECRACK" is provided in Appendix D.

The operator is requested by the program to enter specific specimen data. The program will compute the initial maximum and minimum loads and change in the associated stress intensity factor (delta K). If this delta K exceeds 40 $ksi*in^{1/2}$ then new maximum and minimum loads are computed. The operator is responsible for ensuring the MTS machine is operating within the prescribed limits. The operator can obtain a hard copy of the entered and computed data for record purposes (see Appendix G).

The MTS machine produces cyclic loading by means of an inverted (compressive load) haver sine wave.

The operator must periodically interrupt the cyclic loading and measure the current crack length by manually loading and unloading the specimen (determine the specimen's compliance). The program computes the new crack length and new loading limits. During the last 50% of precracking:

$$P_{max} < .4P_L$$

where

Pmax = maximum load

P_L = [(4/3) * (B * b^2 * Fs / (2 * Hs))]

where

B = net thickness (Bmin if specimen has side grooves)

b = current uncracked ligament (W-a)

Fs = flow stress ((Ys+Uts)/2)

Hs = half span

and Delta_K/E < 0.005 $mm^{1/2}$ (0.001 $in^{1/2}$) whichever, produces the least load [Ref. 5]. The program will automatically begin using these parameters when the most recently calculated crack length exceeds this 50% of the required extension to reach a/W = 0.6. This value is used because it is the optimum crack length with which to begin the J-integral test [Ref. 5].

D. J-INTEGRAL TEST

The J-integral test is performed by slowly applying a load to the specimen and periodically unloading it by 10% of the expected maximum load. The MTS machine is set up in stroke control with a very small inverted ramp function resulting in a loading rate of 0.005 inch/minute. The operator must again interrupt the MTS program and manually unload the specimen. Each unloading cycle (unload and reload) provides the necessary information to compute the current crack length. The crack length is then used to

determine the value of J up to that point. The computer program "J_INTGL" provides the operator with pertinent information during the test. Once the test is completed, the operator can obtain the J-R curve and value of J_{Ic} (see Figure 4 and Appendix H). The program will use only data points between the offsets, (blunting line + 0.15mm) to (blunting line + 1.5mm) as required ASTM Standard E813-81 when computing the linear regression line. A minimum of four data points must be within the offsets and one must lie near (within 1/3 the overall range of delta_a) the blunting line. Specific acceptability criteria for data is provided in ASTM Standard E813-81 [Ref. 5].

The program "J_INTGL" is the foundation of the test method, the single specimen approach would not be possible without it. The program collects, manipulates, displays and records all pertinent data during the test. A flow chart of "J_INTGL" is provided in appendix C. A listing of "J_INTGL" is provided in Appendix E.

Deflection measurements are presently taken using the LVDT installed in the MTS machine. A correction is therefore required to account for the system's compliance while loading a specimen. The correction was obtained by loading the system with a two inch thick piece of HY130 and recording the stroke reading for various loads. This process was checked three times with consistent (within 5%)

results. A plot of the data and the 4th order ploynomial curve fit is included as Figure 5.

E. POST TEST VERIFICATION

The results must be verified upon completion of the test. ASTM Standard E813-81 presents the following criteria that must be met before the test can be considered valid:

1. Total crack extension (visually measured) must be within 15% of that recorded during the test.
2. b_i and Bmin > 25 * J_{Ic} / Fs (all terms are as defined earlier except b_i = post-fatigue uncracked ligament).
3. The slope of the linear regression fit to the data must be less than flow stress (dJ/da < Fs).

IV. RESULTS

A. TEST RESULTS

Specimen HY80-5B, prepared from the base metal of the preheated welded plate, was precracked,and tested resulting in a J_{Ic} value of 142 kJ/m^2. Figure 8 is a tracing of a photograph of the final fracture surface after heat tinting. All post test checks were completed and yielded satisfactory results. The J_{Ic} value is in good agreement with previous tests of HY80 plate as conducted by DTNSRDC resulting in an average J_{Ic} of 144 kJ/m^2 [Ref. 6].

Plots of J-R curve, load versus COD, load versus deflection and the are included as Figures 5, 6 and 7, respectively. The load versus deflection curve was obtained using the program "J_DATA", thus proving that the data is stored on disk, and is able to be recalled.

Data was taken at a nearly constant rate of 2.5 data points per second (150 per minute) while the program was executing.

Test reults were verified following the guidelines provided by ASTM Standard E813-81. The fracture surface was enlarged by taking a photograph, a tracing of which is included as Figure 8. The observed crack length was 14.4% longer than the last recorded crack length. This is within the acceptable limit (recall ASTM requires < 15%) but

because the clip gage reached its limit detector and caused the test MTS to stop between unloadings, it is possible some crack extension occurred after the last unloading cycle. This would help to explain the difference.

Additional information on this specific test is provided by being used in the example calculations shown in Appendix A. The exemplary computer output for each of the programs is also from specimen HY80-5B. (See Appendixes G, H and I).

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The method developed and presented by this work produces accurate and reliable results that meet the specifications established by ASTM Standard E813-81. Precracking specimen HY80-5B took approximately 2 hours and the J-test required approximately 2.5 hours including several pauses to manually verify several calculations. The time required for the processes will most likely decrease as operator experience and confidence increases.

All three computer programs have run successfully and perform as intended.

B. RECOMMENDATIONS

As with all first versions of computer programs as extensive as "J_INTGL", changes and improvements are to be expected. The following programming changes may be of value to future operators:

1. Display pertinent information (i.e. current crack length in both English and metric units (currently only metric is provided).
2. Provide a means of storing the data arrays during the test without being required to rerun the entire

program (re-entering specimen data, conversion data, etc.)

3. Provide a means of eliminating a specific J-R data point from being used in obtaining the linear regression fit. This may be programmed to be accomplished automatically by applying Chauvenet's Criterion to the data.

Improvements in the current means of conducting the test can also be made, such as making the MTS control both loading and unloading using the same rate, requiring the operator to do no more than press a button or throw a switch. Lastly, pursue the use of the external LVDT, this will eliminate the need for correcting the deflection reading and speed up the rate of data acquisition.

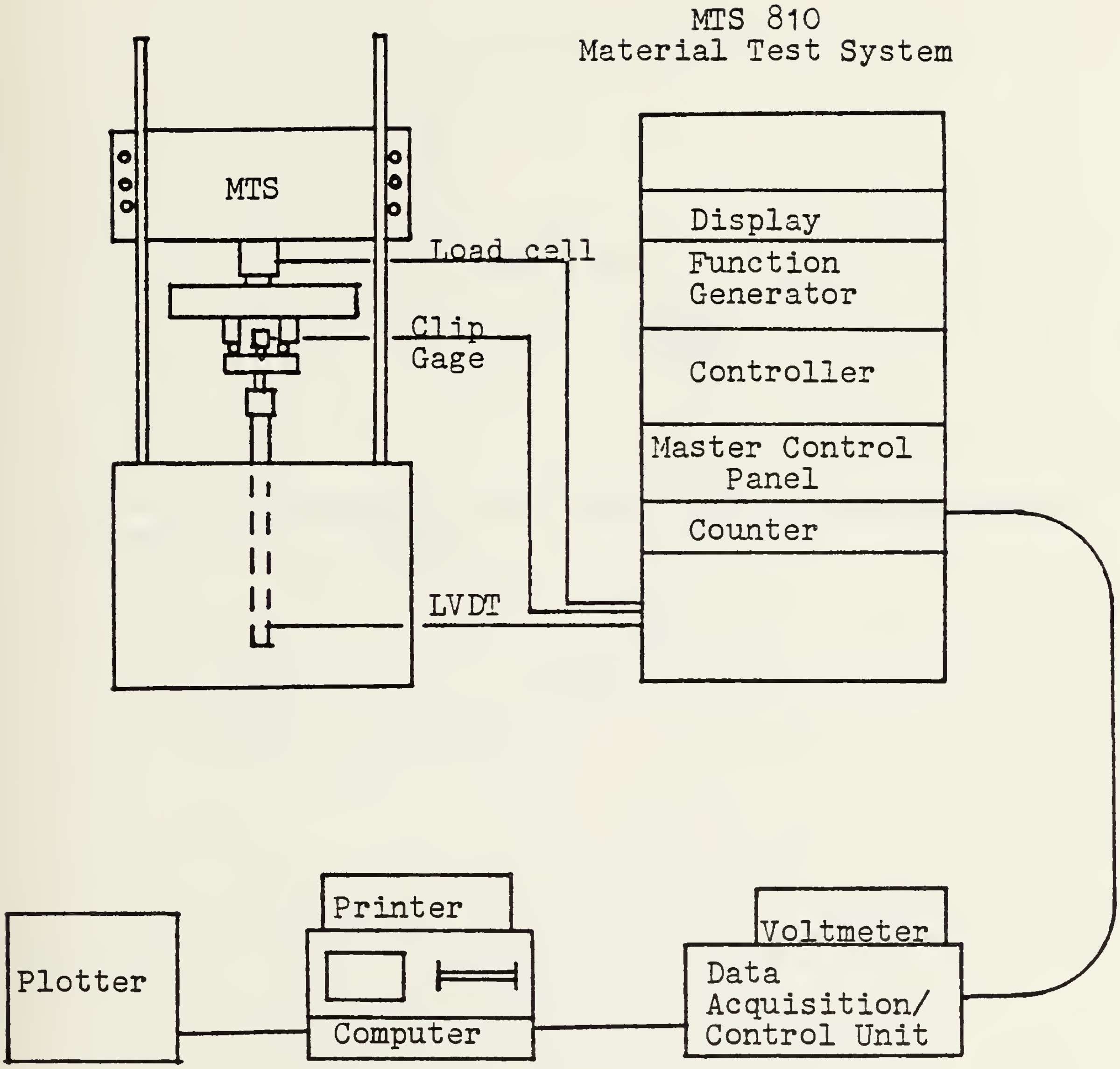


Figure 1. System Layout

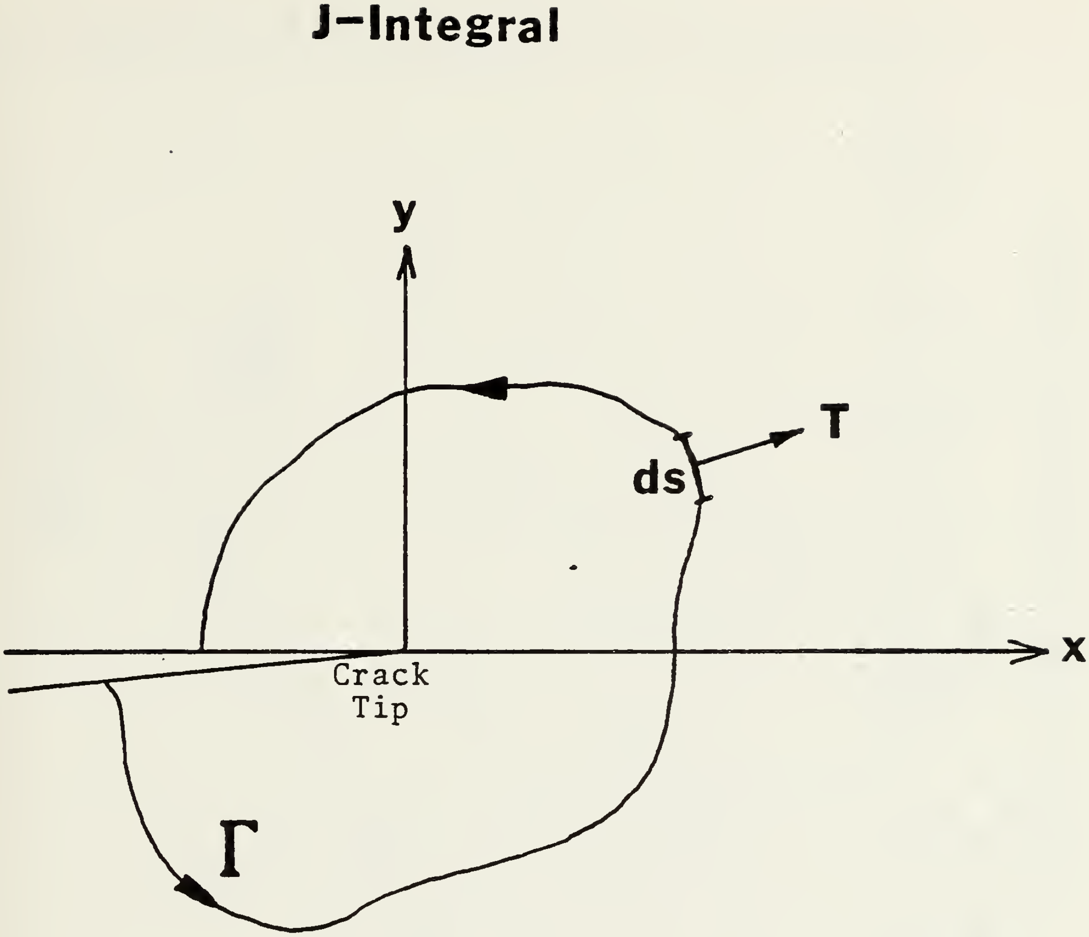


Figure 2. Pictorial Representation of J-Integral

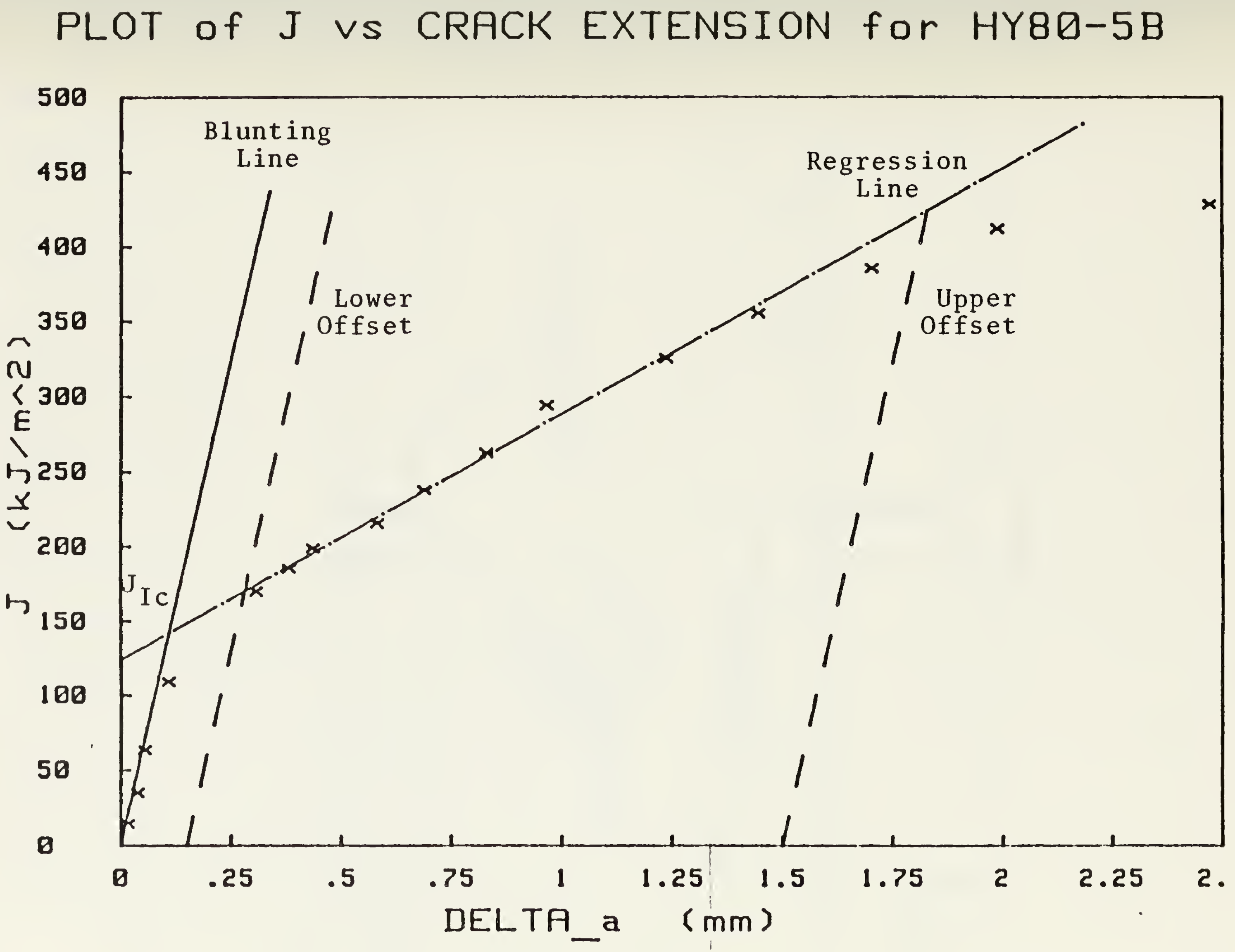


Figure 3. J Versus Crack Extension for HY80-5B

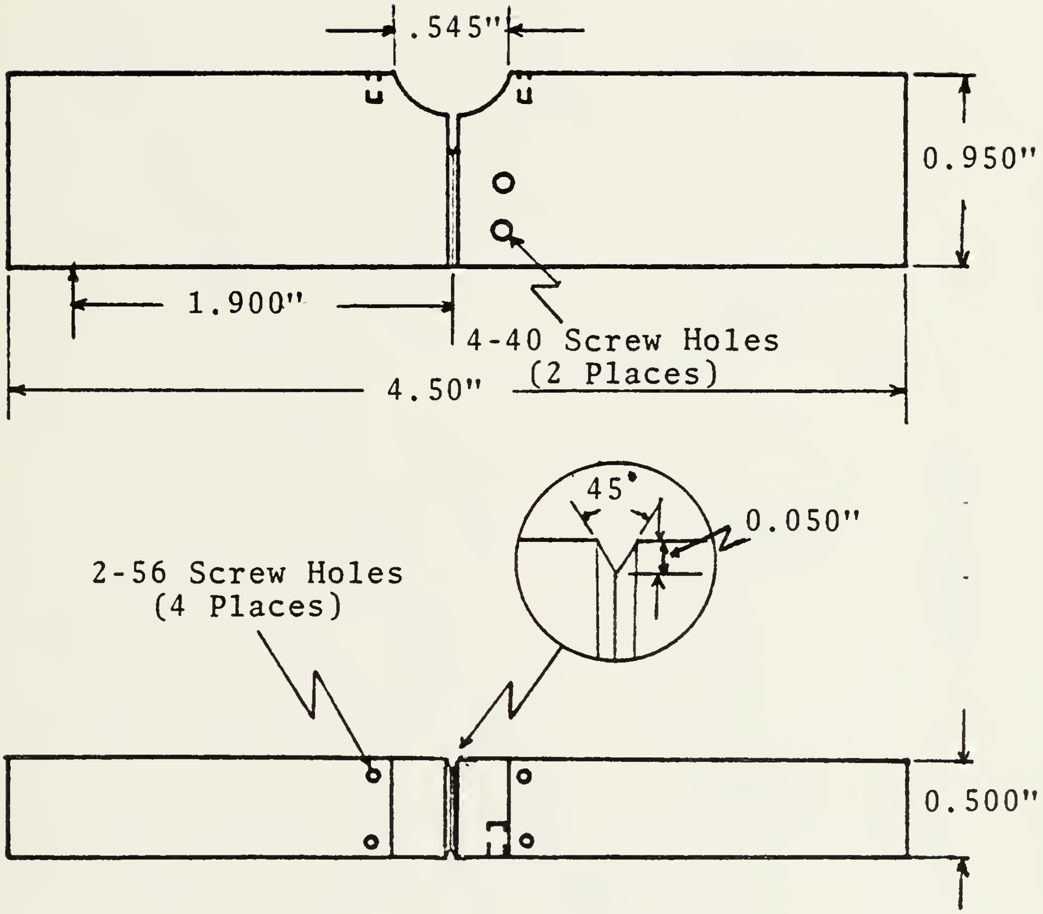


Figure 4. Specimen Drawing

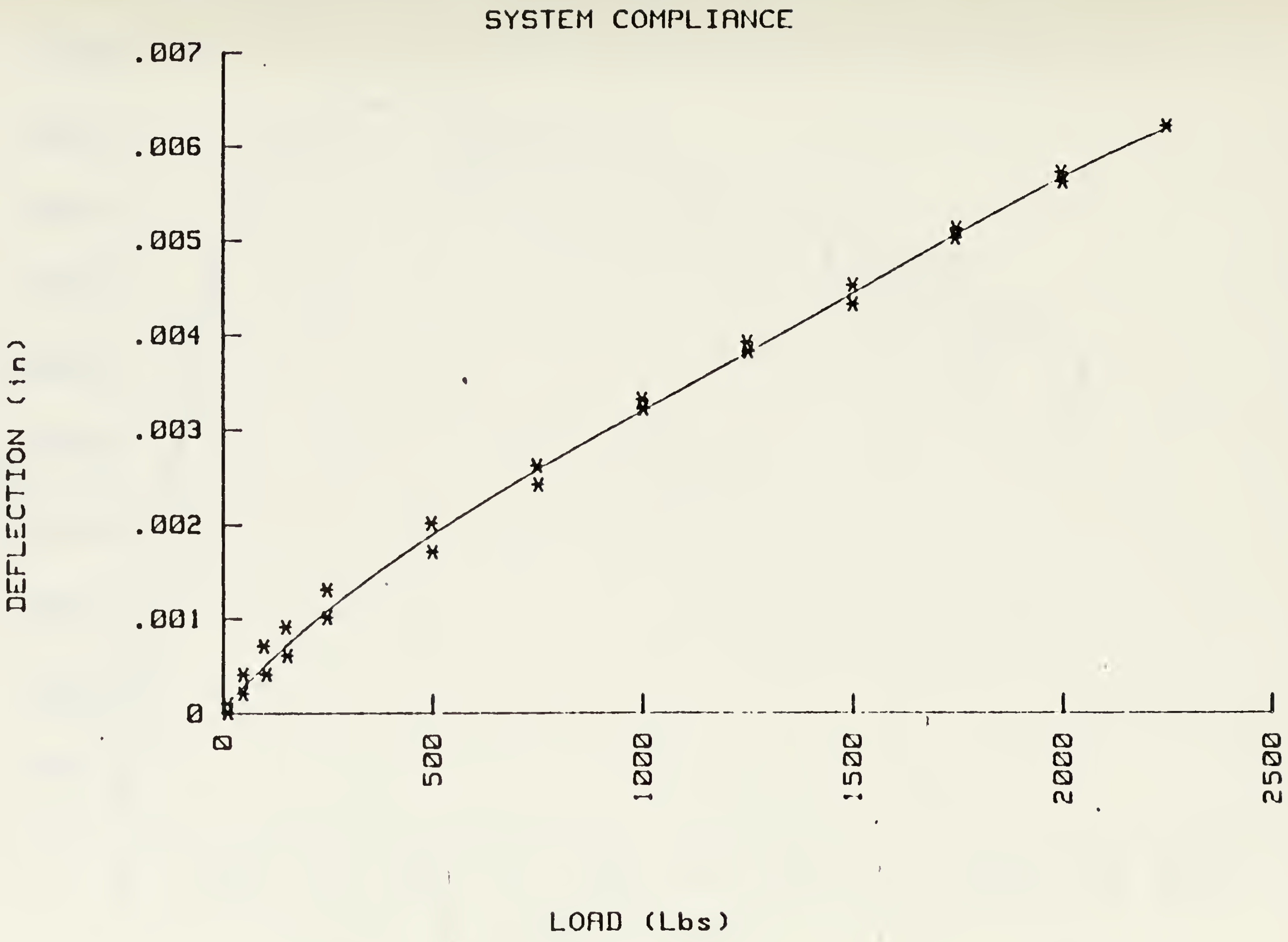


Figure 5. Plot of System's Compliance

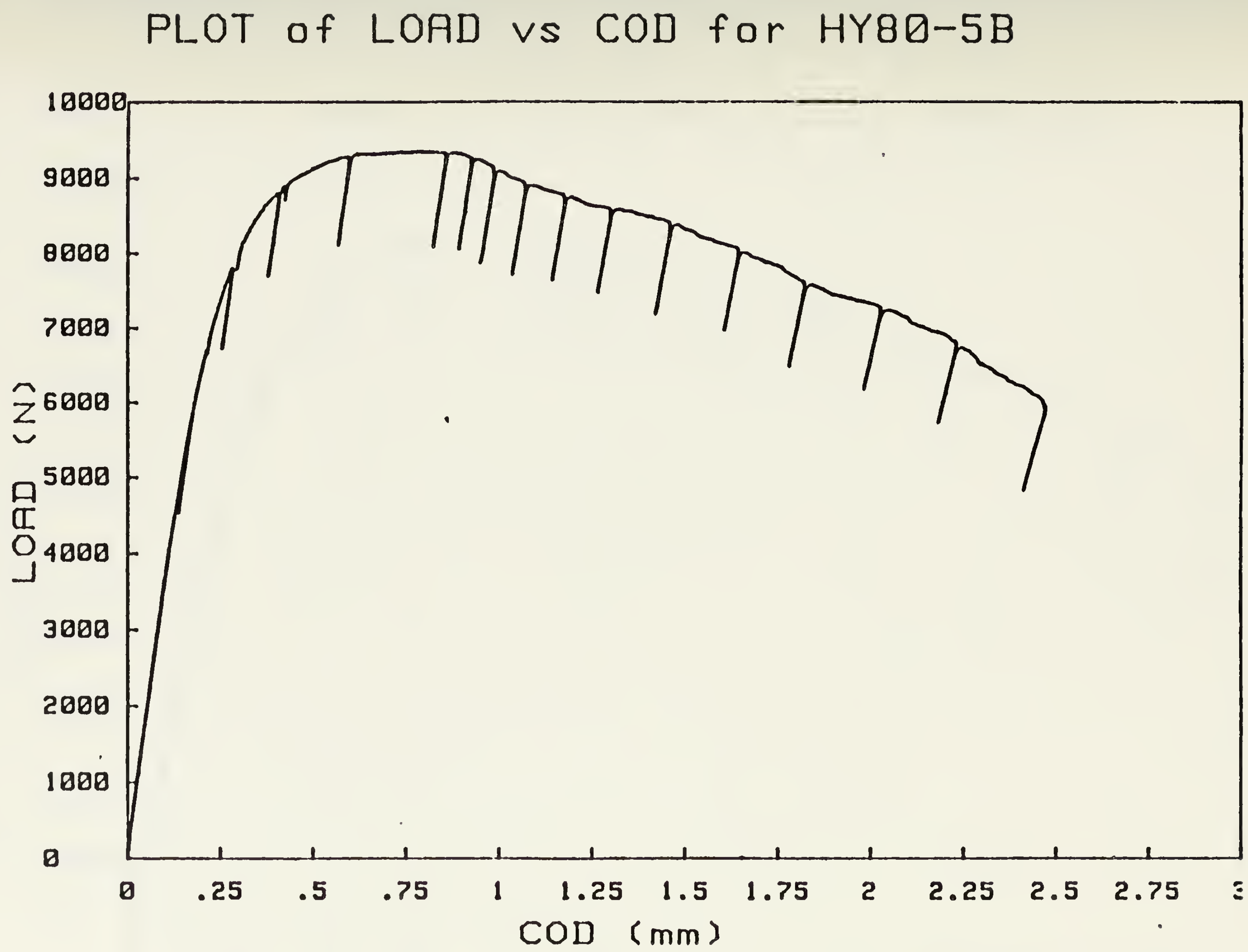


Figure 6. Plot of Load Versus COD for HY80-5B

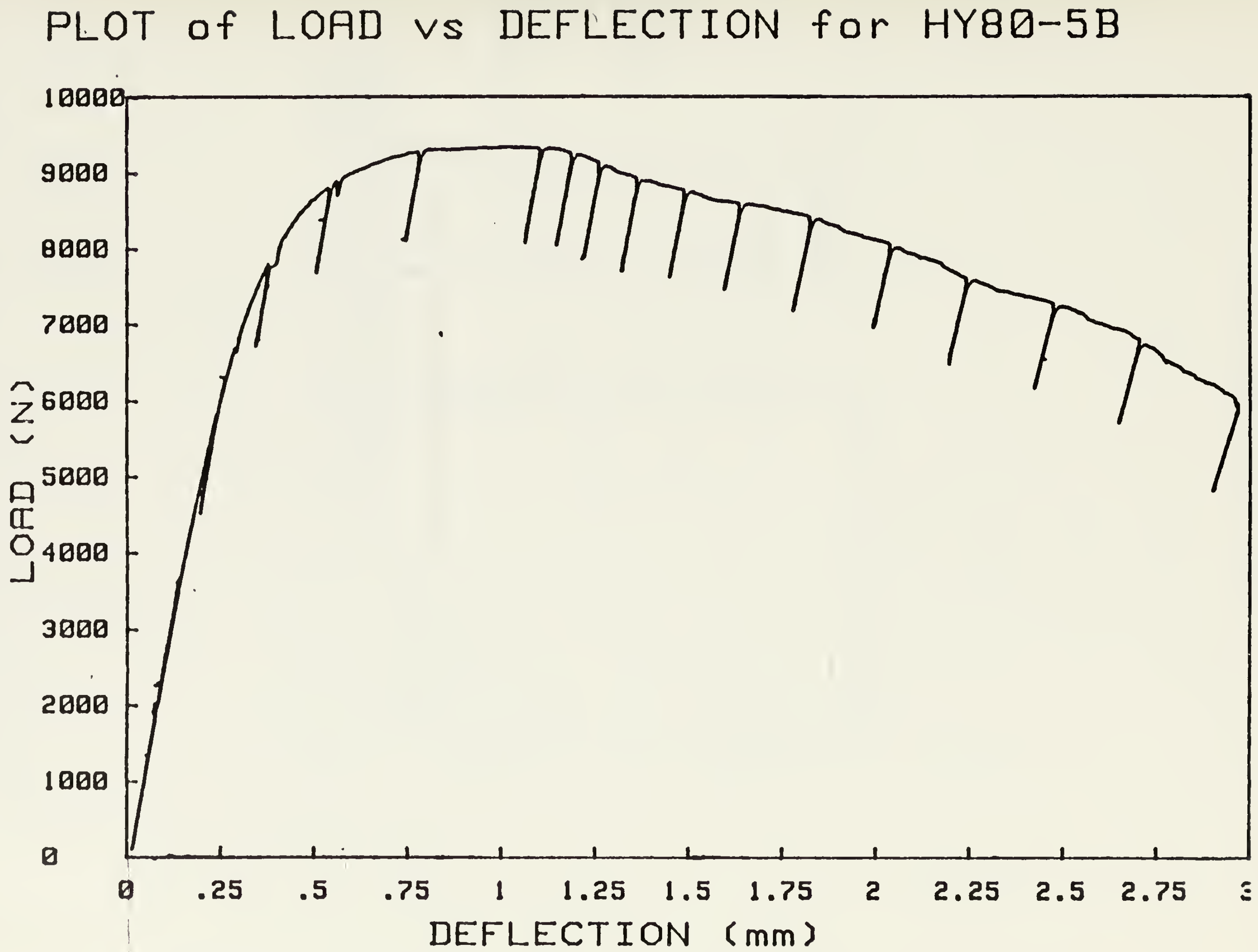
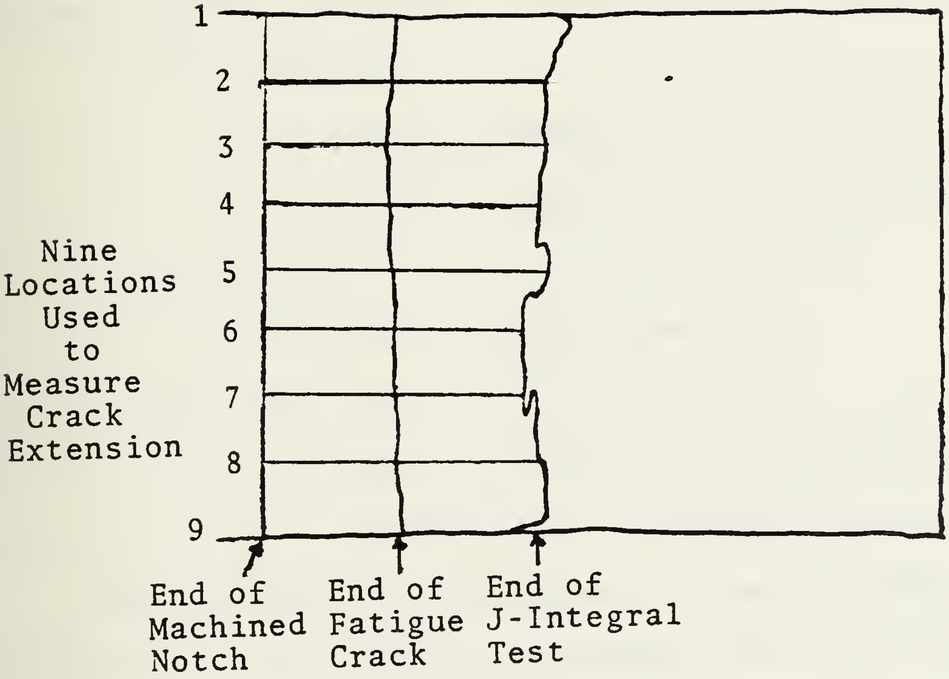


Figure 7. Plot of Load Versus Deflection for HY80-5B



Fracture Surface

Figure 8. Tracing of HY80-5B Fracture Surface

APPENDIX A

TESTING METHODS

A. INTRODUCTION

The steps required to perform a J-integral test using a single specimen approach can be divided into three major categories, pre-test, test, and post test. Each of these categories may be further divided as shown below.

1. Pre-test
    a. Machine specimen
    b. Precrack specimen by fatigue loading
2. Test
    a. Run J-integral test
3. Post-test
    a. Heat tint specimen and break apart
    b. Measure crack extension and verify results

Each process is described in greater detail in this appendix. A working knowledge of the equipment is presupposed and awareness of all safety precautions is required before operating the MTS.

B. PRE-TEST

a. Machine Specimen

ASTM Standard E813-81 provides very specific guidance on specimen dimensions. All dimensions are related to the

width (W). Fatigue precracking is enhanced if the radius at the tip of the notch is kept to approximately 0.003 inches. This was accomplished by machining with a special cutter which was used to make only the final passes in the notch. Figure 2 can be consulted for the actual dimensions used to machine the specimens used in this work.

b. Precracking

The following step by step guide is provided to assist operators.

1. Before turning on the MTS machine ensure the proper range card is installed in the strain signal conditioner for the clip gage to be used.
2. Turn on power to all equipment with the computer being switched on last.
3. Load and run "PRECRACK" program on the HP-9826 computer.
4. Select range scales on MTS;

example: 10 v = 4000 lbs 20% of full load (range #3)
10 v = 0.02 in 10% of full clip gage (range #4)
10 v = 2.5 in 50% of full stroke (range #2)

5. Press k0-key on computer and enter specimen data as requested.
6. Press k2-key and enter conversion data as requested.
7. Press k5-key to obtain a table of COD readings for various loads and crack lengths.
8. Set READOUT knobs on the MTS Controller to be:

top = load

middle = strain

bottom = stroke

Set all to (+) polarity. See Figure A1. This ensures channels of the MTS machine are properly aligned with the data acquisition system.

9. Set MTS limit detector switches based on the information just generated by the program. Limit switch settings are determined by the simple formula:

Limit switch = L * 10 / FSR

where

L = desired limit in English units

FSR = full scale range of current operating being used in English units

example "PRECRACK" determined:

Pmax = 1668 lbs set load limit to 1600 lbs for specimen HY80-5B

load limits:

upper limit --- small positive load for example 40 lbs (should never be positive)

+40 lbs * 10 v / 4000 lbs = +0.1 v

therefore set upper limit knob to +0.1 v

lower limit --- 1600 lbs maximum load

-1600 lbs * 10 v / 4000 lbs = -4.0 v

therefore set lower limit knob to -4.0 v

strain limits:

upper limit --- 0.01 in beyond maximum expected during precracking

+0.01 in * 10 v / 0.02 in = +5.0 v

lower limit --- some small value for example -0.1 v (should never be negative)

stroke limits:

upper limit --- 1.5 in to allow clearance for installing specimen and yet stop the MTS if this limit is reached

+1.5 in * 10 v / 2.5 in = +6.0 v

lower limit --- 0.25 in of compressive actuator movement is more than sufficient for precracking

-0.25 in * 10 v / 2.5 in = -1.0 v

10. Adjust the upper roller supports as required to obtain a span-to-width ratio (S/W) of 4.0.

11. Install specimen (with the clip gage already installed) using alignment collars to properly center.

12. Zero the load and strain voltages.

13. Reset and clear all limit switches (all green lights on controller panel should be showing).

14. Using load control energize hydraulics and apply a low (<100 lbs) compressive load to the specimen by SLOWLY turning the SETPOINT knob counter-clockwise.

15. Slowly decrase the compressive load on the specimen to between 5 and 10 lbs by turning the SETPOINT knob clockwise and then zero the stroke voltage reading.

YOU ARE NOW READY TO OBTAIN AN UNLOADING COD COMPLIANCE MEASUREMENT OF THE CRACK LENGTH

16. Press k4-key on the computer and proceed with taking data.

17. Slowly, and as smoothly as possible increase the load to approximately 500 lbs and return to approximately 20 lbs ending the loading cycle with a slight (10 lbs) increase to trip the computer out of the data-taking loop.

The computer will display all pertinent crack length information and ask if you want another measurement. You may repeat this process as often as you like, just be sure the maximun load is lower than that required to extend the crack.

18. Make necessary adjustments to the MTS such that the strain limit switch will trip the MTS when the crack extends to 50% of the desired extension. This is determined by interpolating results from the table obtained earlier. (See Step 7).

NOTE: As the crack propagates the acceptable maximum load decreases. For the specimen, HY80-5B, used to test this program a Pmax = 1000 lbs was suitable to initiate the crack and propagate it to 50% of the desired extension (a = 0.506 in).

Example:

50% crack extension = crack length (a) of 0.506 in

from table:

COD = 1.7 volts at 1000 lbs and a = 0.506 in

Therefore set UPPER STRAIN LIMIT SWITCH to +1.7 v.

YOU ARE NOW READY TO BEGIN CYCLIC LOADING

19. Setup MTS:

DISPLAY:

a. Setup to read maximum and minimum load in lbs.

FUNCTION GENERATOR:

a. CONTROL MODE: Remote
b. RATE 1: 10 Hz
c. RATE 2: N/A
d. HOLD BUTTON: In
e. BREAKPOINT: N/A
f. HAVER SINE: In
g. INVERT: In

CONTROLLER :

a. SPAN 1: 0.0
b. SPAN 2: 0.0

COUNTER:

a. COUNTER INPUT: Oscillator
b. COUNTER MULTIPLIER: X100
c. Press RESET

20. Slowly increase the SETPOINT to Pmin.

21. Press the RUN button on the CONTROLLER and then release the HOLD button of the FUNCTION GENERATOR.

22. Slowly increase the span of the cyclic loading using SPAN 1 knob to the desired Pmax.

The MTS will continue cyclic loading until it is manually stopped or a limit detector is tripped. Most likely the COD limit detector will trip at which time the machine will will stop and unload the specimen.

23. A new crack length measurement can now be obtained using the same manual process as described in Step 16 and Step 17.

24. Readjust limit switches and resume fatigue loading as done in Steps 18 through 22.

25. Continue this process until the crack reaches the desired length.

C. J-INTEGRAL TEST

The following steps are required to run a J-integral test. They are very similar to those used in precracking. The major change is that a ramp function under stroke control is now used to control the MTS machine.

1. Before turning on the MTS machine ensure the proper range card is installed in the strain signal conditioner for the clip gage to be used.

2. Turn on power to all equipment with the computer being switched on last.

3. Load and run "J_INTGL" program on the HP-9826 computer.

4. Select range scales on MTS;

example: 10 v = 4000 lbs 20% of full load (range #3)

10 v = 0.02 in 10% of full clipgage (range #4)

10 v = 0.5 in 10% of full stroke (range #2)

5. Press k0-key on computer and enter specimen data as requested.

6. Press k1-key and enter conversion data as requested.

7. Press k3-key and follow instructions for creating a data file on an initialized data diskette. See HP-Mannual on how to initialize a diskette if necessary.

8. Press k3-key to setup the plotter.

9. Press k5-key and obtain the maximum load you may apply while measuring a0.

YOU ARE NOW READY TO SETUP THE MTS MACHINE

10. Set READOUT knobs on the MTS Controller to be:

top = load

middle = strain

bottom = stroke

Set all to (+) polarity. See Figure A1.

11. Set MTS limit detectors switches.

example:

Pmax = 895 lbs for HY80-5B (see Appendix H)

load limits:

upper limit --- small positive load (40 lbs)
(should never be positive)

+40 lbs * 10 v / 4000 lbs = +0.1 v

lower limit --- 895 lbs compression maximum

-895 lbs * 10 v / 4000 lbs = -2.125 v

strain limits:

upper limit --- want to be able to read full scale on range #2 (0.1 in)

+0.1in * 10 v / 0.1 in = +10 v

lower limit --- a very small value set to -0.1 v

(should never be negative)

stroke limits:

upper limit --- full scale (+10.0 v) on this most sensitive scale

lower limit --- a maximum compression of 0.25 in is sufficient for the test and will stop the actuator before it can cause any serious damage to the specimen holder

-0.25 in * 10 v / 0.5 in = -5.0 v

12. Adjust the upper roller supports as required to obtain a span-to-width ratio of 4.0.
13. Install the specimen (with the clip gage already installed) using the alignment collars to properly center.
14. Zero the load and strain voltages.
15. Reset and clear all limit switched (all green lights on controller panel should be showing).
16. Using load control energize hydraulics and apply a low (<100 lbs) compressive load to the specimen by SLOWLY turning the SETPOINT knob counter-clockwise.
17. Decrease the load to between 5 and 10 lbs and zero the stroke voltage.

18. Adjust the MTS to the following settings:

DISPLAY:

a. Setup to read load in lbs and stroke in inches.

FUNCTION GENERATOR:

a. CONTROL MODE: Remote
b. RATE 1: 6000 (sec)
as determined by: desire 0.005 in/min loading rate therefore;

0.5 in (full scale) / 0.005 in/mim * 60 sec/min = 6000 sec

c. RATE 2: N/A
d. HOLD BUTTON: In
e. BREAKPOINT: N/A
f. RAMP BUTTON: In
g. INVERT: IN

CONTROLLER:

a. SPAN 1: 10.0 (full scale)
b. SPAN 2: 0.0

COUNTER: N/A

YOU ARE NOW READY TO MEASURE THE INITIAL CRACK LENGTH

19. The computer will begin taking data after the 'CONTINUE' key is pressed. The MTS will begin loading the specimen after the MTS' RUN switch is pressed and the HOLD button is released.

20. When the desired maximum load (approximately 500 lbs) is reached; depress the HOLD button, switch to load control, and manually decrease the load (to approximately 20 lbs) by SLOWLY turning the SETPOINT knob clockwise. As with precracking you must end the unloading with a small increase in load (10 lbs from where you stop) to signal the computer you have completed the load/unload cycle. The computer will

plot the data as you go, ensure you remain on the linear portion of the loading curve.

21. The computer will display all the pertinent crack length information. You may repeat this operation by switching back to stroke control and repeating Steps 19 and 20 as often as you like as long as you remain on the linear portion of the loading curve.

22. After the computer has stored the desired initial crack length (a0) measurement on data diskette, you are ready to begin propagating the crack.

23. Ensure you are in stroke control with near zero (<10 lbs) load and the RUN light is on with the HOLD button depressed.

24. Press the k7-key on the computer follow instructions and proceed to collecting data (data acquisition system will be continuosly switching channels and the plotter will be plotting), now release the HOLD button on the MTS.

25. When you reach a point where you wish to unload the specimen; press the HOLD button, switch to load control, and slowly decrease the load. The computer will beep when you have unloaded the specimen by 10% of the expected maximum load. Switch back to stroke control and release the HOLD button to reload the specimen.

26. When the load returns to the point from which the unloading began the computer will display and printout all

the information it has determined with regards to the current unloading cycle.

27. This process of switching control modes (Steps 25 and Step 26) are repeated for every unloading cycle until the you decide to stop by pressing the k9-key on the computer or one of the limit detectors shuts off the MTS machine. Remember, you must have atleast four data points between the offsets one of which lies near the blunting line on the J-R curve.

28. The k9-key interrupts the computer program and tells it to stop taking data and write the data it has collected on the data diskette.

29. The computer will then display a table of the collected J versus delta_a and ask if you desire a plot. Simply follow the directions from the computer and you will obtain the J-R curve and the value of J_{Ic}.

D. POST-TEST

The post-test includes verifying the final crack length, and validating the other parameters as discussed in ASTM Standard E813-81 such as:

$$b_i \text{ and } B_{min} > 25 * J_{Ic} / Fs$$

where

b_i = uncracked ligament after precracking

Bmin = minimum specimen thickness

Fs = flow stress

and that the slope of the linear regression fit to the data is less than the flow stress (dJ/da < Fs). This data is obtained directly from the "J_INTGL" program output.

Heat tinting the specimen, 10 minutes at 300C for most steels, aids in the visual identification of the amount of crack extension. After the specimen is removed from the oven and air cooled, place it in liquid nitrogen to assist in obtaining a brittle fracture. After breaking the specimen apart, place the pieces in alcohol while returning to room temperature. This will prevent water vapor from condensing and freezing on the surface and minimize oxidation.

A photographic enlargement of the surface can now be obtained and the crack length can easily be verified. The final crack extension must be within 15% of that recorded during the test.

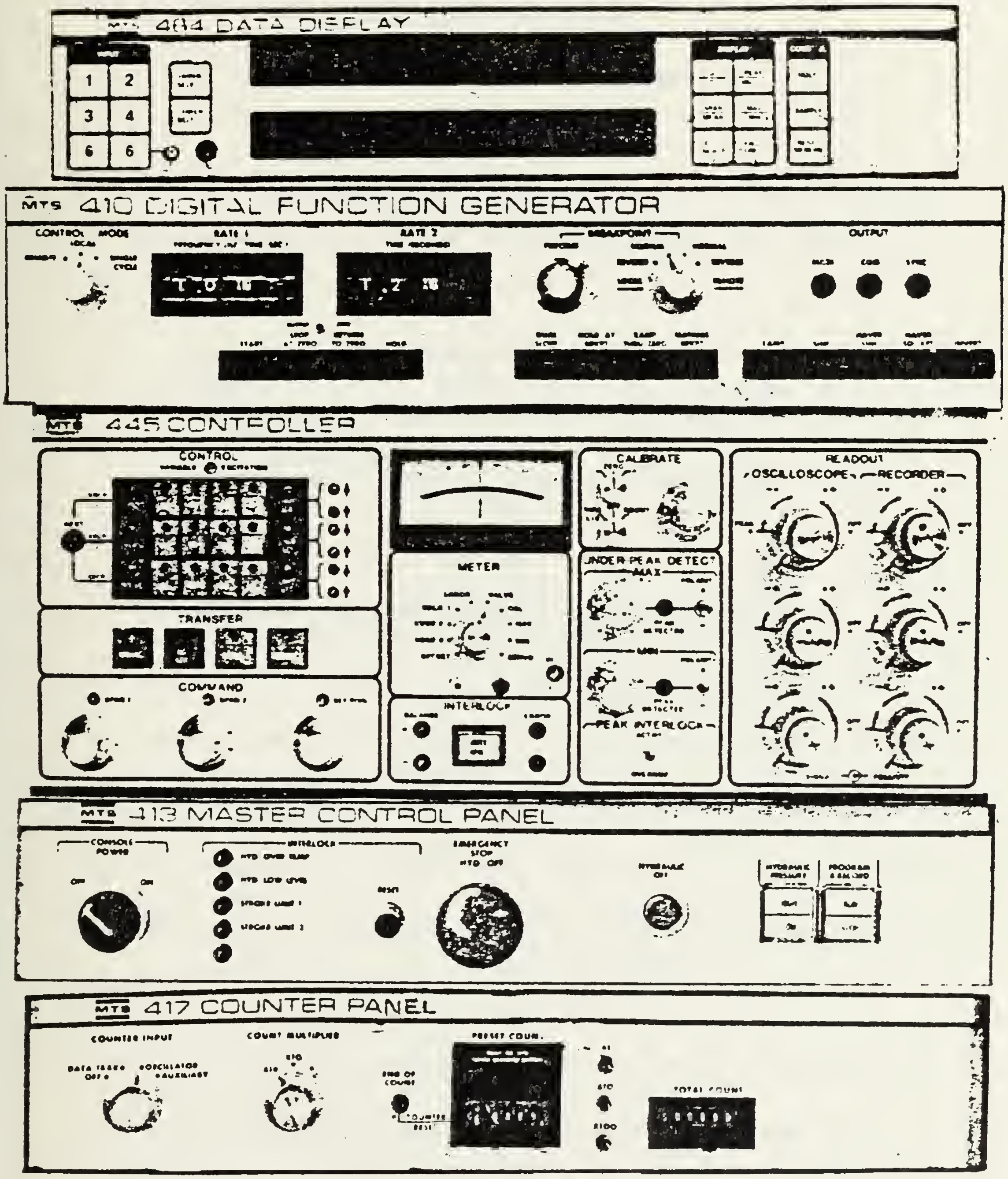


Figure A1. MTS Control Panel

APPENDIX B

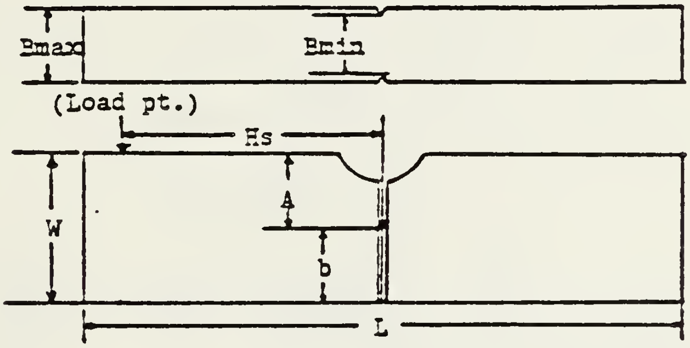
TEST RECORD SHEET

THREE POINT BEND SPECIMEN

TEST REPORT

SPECIMEN I.D. ____________ MATERIAL ______________ ORIENTATION _____

Date ________________ Operator __________________ Test Temp ________



W = ___________ A = ___________ b = ___________ L = ___________

Hs = ___________ Bmax = ___________ Bmin = ___________

Ys = ________________ Uts = ______________ Fs = _______________

Poisson's ratio = __________ Elastic Modulus = ________________

Comments:

____

____

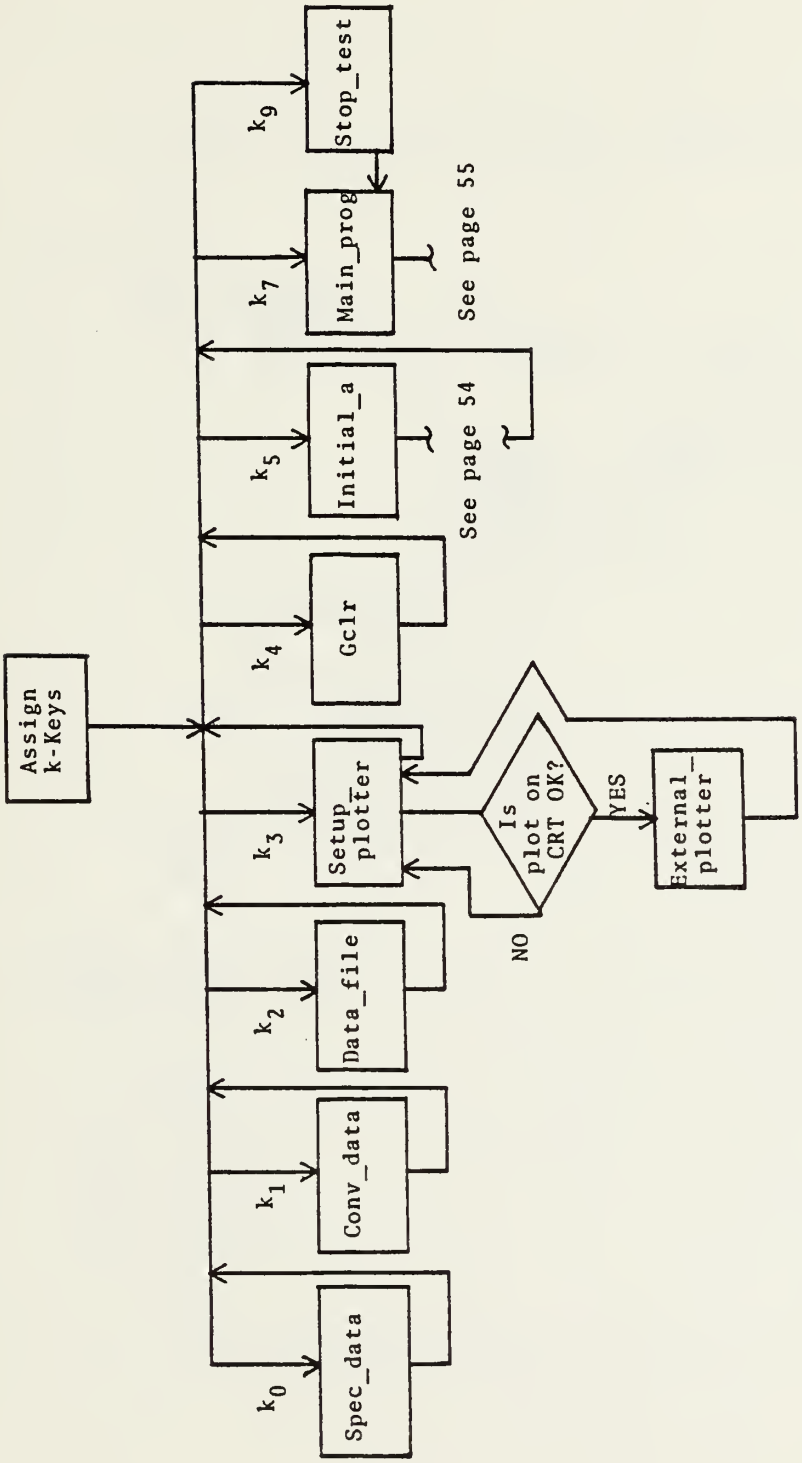
____

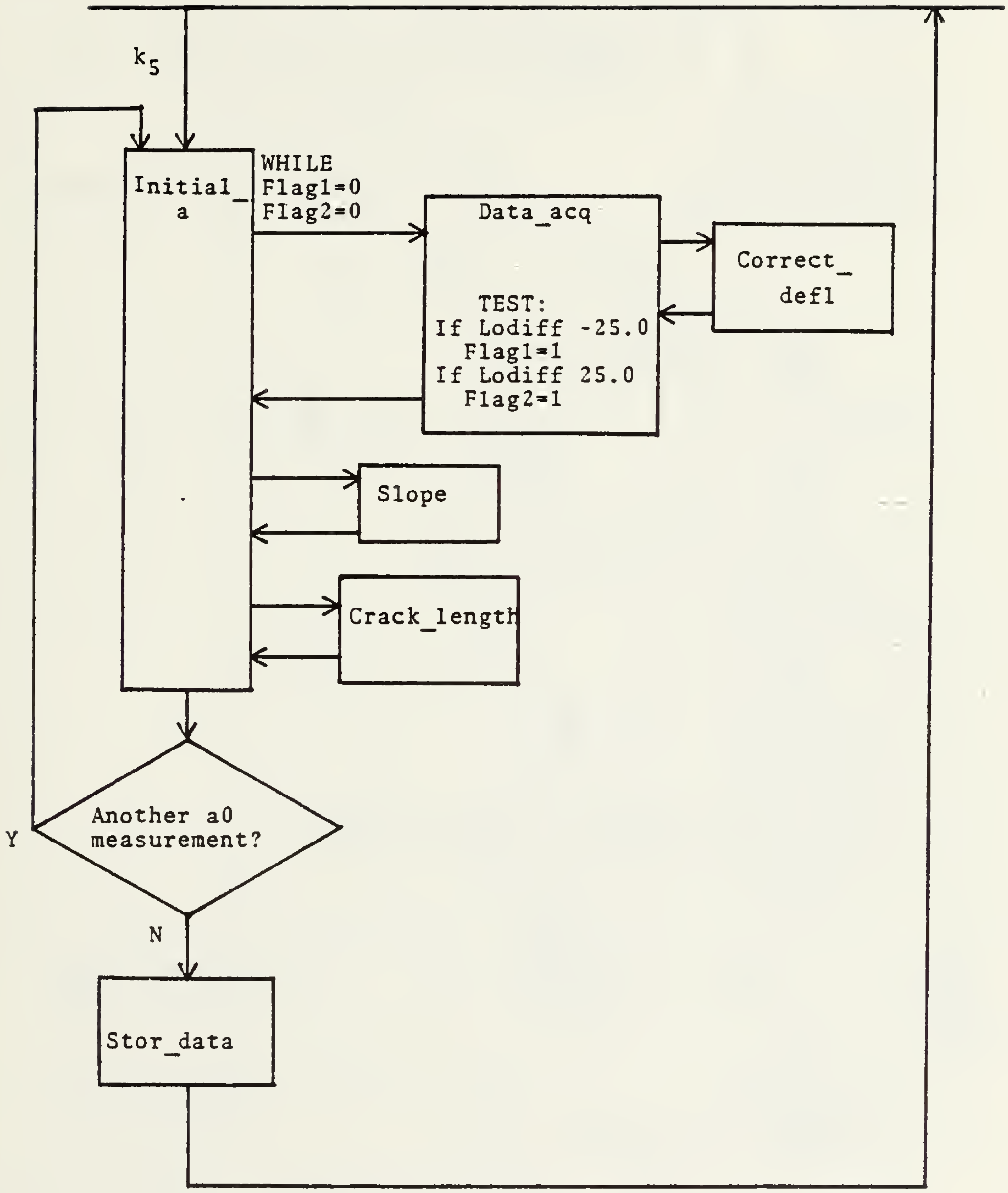
____

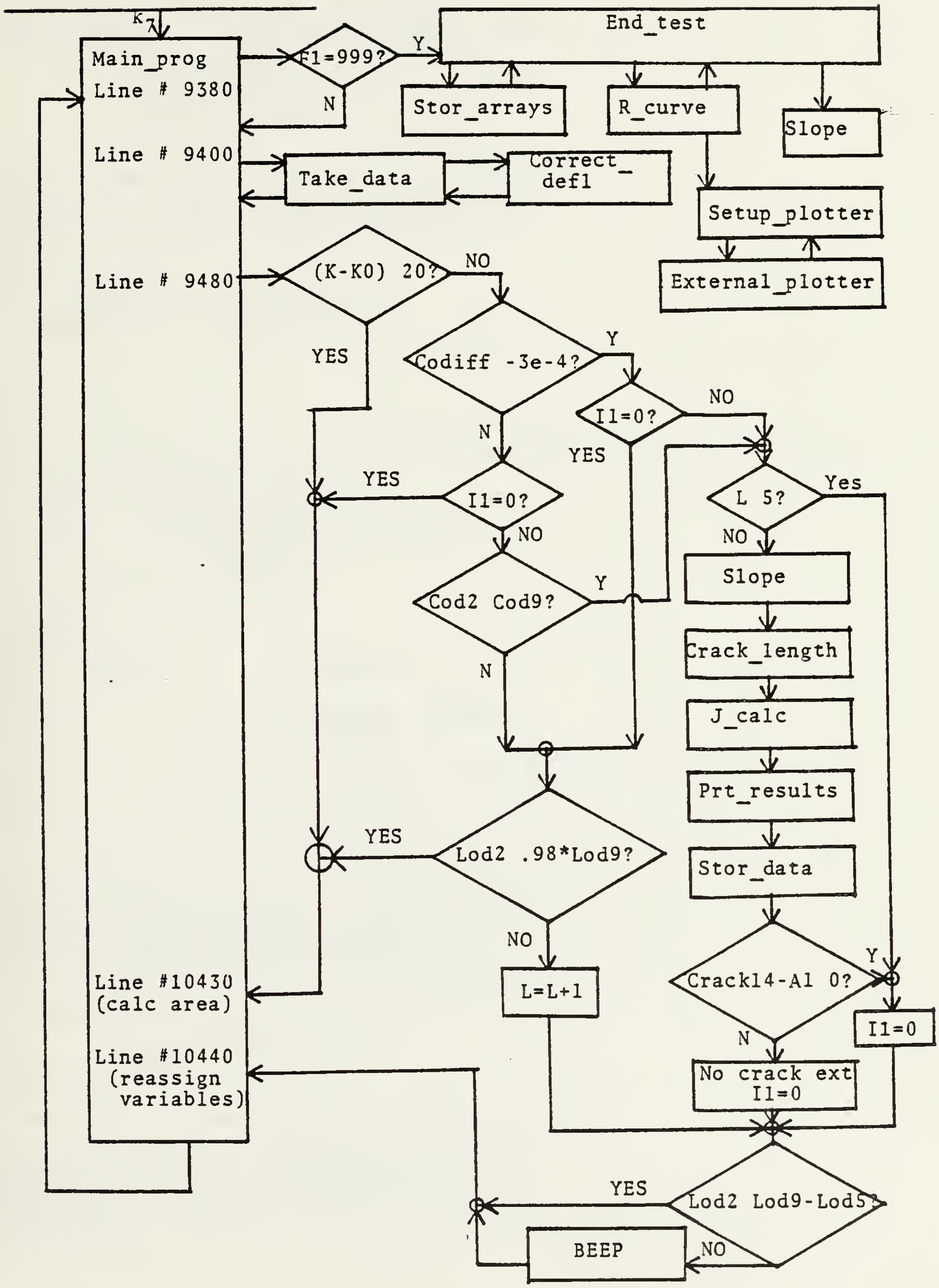
APPENDIX C

J_INTGL FLOW CHART

"J_INTGL" FLOW CHART




k5
Initial_
a
WHILE
Flag1=0
Flag2=0
Data_acq
TEST:
If Lodiff -25.0
Flag1=1
If Lodiff 25.0
Flag2=1
Correct_
defl
Slope
Crack_length
Another a0
measurement?
Y
N
Stor_data


K
Main_prog
Line # 9380
Line # 9400
Line # 9480
Line #10430
(calc area)
Line #10440
(reassign
variables)
F1=999?
Y
N
End_test
Stor_arrays
R_curve
Slope
Take_data
Correct_
defl
Setup_plotter
External_plotter
(K-K0) 20?
NO
YES
Codiff -3e-4?
Y
N
I1=0?
NO
YES
I1=0?
YES
NO
Cod2 Cod9?
Y
N
L 5?
Yes
NO
Slope
Crack_length
J_calc
Prt_results
Stor_data
Lod2 .98*Lod9?
YES
NO
L=L+1
Crack14-A1 0?
Y
N
I1=0
No crack ext
I1=0
Lod2 Lod9-Lod5?
YES
NO
BEEP

APPENDIX E

PRECRACK LISTING

```
10     ! PRECRACKING PROGRAM FOR THREE POINT
20     ! BEND SPECIMEN. THIS PROGRAM INCORPORATES
30     ! THE USE OF THE FOLLOWING EQUIPMENT:
40     !      1. HP-9826 COMPUTER
50     !      2. HP-3497A DATA ACQUISITION SYSTEM
60     !      3. HP-2671G THERMAL PRINTER
70     !      4. MTS MACHINE
80     !
90     ! THE PROGRAM USES BOTH ENGLISH AND METRIC
100    ! UNITS. ALL METRIC VARIABLES ARE DENOTED
110    ! WITH AN m IN THEIR NAME ie Wm=WIDTH IN
120    ! METRIC UNITS (mm IN THIS CASE).
130    !
140    ! THIS PROGRAM WAS WRITTEN BY:
150    !     LCDR W. K. TRITCHLER, USN
160    ! VERSION 1.0     DATE 11/33
170    !
180    !
190    !
200    COM /J_intgl/ FI
210    !
220    ! DIM Lodm(2000).Deflm(2000).Codm(2000) these arrays will be dimensioned
230    ! required in the New_a routine.
240    ! Lodm(I) = LOAD IN NEWTONS
250    ! Deflm(I) = DEFLECTION IN mm
260    ! Codm(I) = CRACK OPENING DISPLACEMENT IN mm
270    !
280    DIM Coef(6).G(6).A0(100)
290    DUMP DEVICE IS 706
300    Dvm=709
310    CLEAR Dvm
320    PRINT CHR$(12)        ! CLEARS CRT
330    PRINT ""
340    PRINT "                PRECRACKING  PROGRAM"
350    PRINT "                     VERSION 1.0"
360    PRINT ""
370    PRINT "          WRITTEN BY LCDR W.K. TRITCHLER"
380    PRINT ""
390    PRINT "                PLEASE SELECT A k-KEY"
400    !
410    !*******************************************
420 Begin: !
430    ON KEY 0 LABEL "SPEC_DATA" GOSUB Spec_data
440    ON KEY 2 LABEL "CONV_DATA" GOSUB Conv_data
450    ON KEY 4 LABEL "NEW_A" GOSUB New_a
460    ON KEY 5 LABEL "a_TABLE" GOSUB A_table
470    !
480    !*******************************************
490    !
500 Spin:      ! WAITS FOR KEY INPUT
510    GOTO Spin
520    !
530    !*******************************************
540    !
550 Spec_data:   ! INPUTS REQUIRED SPECIMEN DATA
560    PRINT CHR$(12)        ! CLEARS CRT
570    PRINT "INPUT SPECIMEN IDENTIFICATION (ID):"
580    INPUT D$
590    PRINT ""
```

```
600    PRINT "J-INTEGRAL TEST for ";D$
610    PRINT ""
620    PRINT "INPUT SPECIMEN DATA USING ENGLISH UNITS (LBS.      INCHES. etc.)"
630    PRINT ""
640    PRINT "WHAT IS THE SPECIMEN'S WIDTH. NOTCH LENGTH, Bmax.  Bmin (THICKNESS)
?"
650      INPUT W.A.Bmax.Bmin
660     PRINT ""
670    PRINT "WHAT IS THE SPECIMEN'S HALF SPAN AND POISSON'S     RATIO?"
680      INPUT Hs,Nu
690    PRINT ""
700    PRINT "WHAT IS THE SPECIMEN'S ELASTIC MODULUS. YIELD      STRENGTH AND ULT
IMATE STRENGTH?"
710      INPUT E.Ys.Uts
720    PRINT CHR$(12)              ! CLEARS CRT
730    Fs=(Ys+Uts)/2
740    PRINT "USING ENGLISH UNITS (in.lbs.psi)"
750    PRINT "THE FOLLOWING HAS BEEN ENTERED for: ";D$
760    PRINT "WIDTH =";W;"    NOTCH LENGTH =";A
770    PRINT "Bmax =";Bmax;"         Bmin =";Bmin
780    PRINT "HALF SPAN =";Hs;"   POISSON'S RATIO =";Nu
790    PRINT "YIELD STRENGTH =";Ys;"  ULTIMATE TS =";Uts
800    PRINT "ELASTIC MODULUS =";E;"   FLOW STRESS =";Fs
810    PRINT ""
820    PRINT "THIS PROGRAM ALLOWS NO EASY RECOVERY. IF ANY DATA IS INCORRECT YOU
MUST RE-ENTER ";
830    PRINT "EVERYTHING."
840    PRINT ""
850    PRINT "IS ALL DATA CORRECT?"
860    INPUT H$
870    IF H$="NO" OR H$="N" THEN 550   ! REPEATS Spec_data
880    PRINT ""
890    PRINT "DO YOU WANT A HARD COPY?"
900    INPUT H$
910    IF H$="N" OR H$="N" THEN 1060
920    !
930    PRINTER IS 706            ! TOGGLES PRINTER TO THERMAL PRINTER
940    PRINT ""
950    PRINT "USING ENGLISH UNITS (in.lbs.psi) THE FOLLOWING INFORMATION"
960    PRINT "HAS BEEN ENTERED FOR: ";D$
970    PRINT ""
980    PRINT "WIDTH =";W;"       NOTCH LENGTH =";A
990    PRINT "Bmax =";Bmax;"       Bmin =";Bmin
1000   PRINT "HALF SPAN =";Hs;" POISSON'S RATIO =";Nu
1010   PRINT "YIELD STRENGTH =";Ys;" ULTIMATE TS =";Uts
1020   PRINT "ELASTIC MODULUS =";E;" FLOW STRESS =";Fs
1030   PRINT ""
1040   PRINTER IS 1          ! TOGGLES PRINTER BACK TO CRT
1050   !
1060   PRINT CHR$(12)      ! CLEARS CRT
1070   !
1080   ! CONVERSION TO METRIC UNITS
1090   Conlen=25.4              ! 1in = 25.40mm
1100   Wm=W*Conlen
1110   Am=A*Conlen
1120   Bmaxm=Bmax*Conlen
1130   Bminm=Bmin*Conlen
1140   Hsm=Hs*Conlen
1150   Conpress=6.89475293       ! 1psi = 6.89475293kPa (HP PROGRAMING BOOK)
1160   Em=E*Conpress
```

```
1170  Ysm=Ys*Conpress
1180  Utsm=Uts*Conpress
1190  Fsm=Fs*Conpress
1200  !
1210  PRINT "CONVERTING THIS DATA TO METRIC UNITS (mm.N.KPa)      for ";D$;" YIEL
DS:"
1220  PRINT "WIDTH =";Wm;"    NOTCH LENGTH =";Am
1230  PRINT "Bmax =";Bmaxm;"        Bmin =";Bminm
1240  PRINT "HALF SPAN =";Hsm;"    POISSON'S RATIO =";Nu
1250  PRINT "YIELD STRENGTH =";Ysm;"  UTILMATE TS =";Utsm
1260  PRINT "ELASTIC MODULUS =";Em;"  FLOW STRESS =";Fsm
1270  PRINT ""
1280  PRINT "DO YOU WISH TO HAVE A PRINT OUT OF THIS DATA?"
1290  INPUT G$
1300  IF G$="N" OR G$="NO" THEN 1410
1310  !
1320  PRINTER IS 706               ! TOGGLES TO THERMAL PRINTER
1330  PRINT "CONVERTING THIS DATA TO METRIC UNITS (mm.N.KPa) FOR: ";D$
1340  PRINT "WIDTH =";Wm;"      NOTCH LENGTH =";Am
1350  PRINT "Bmax =";Bmaxm;"    Bmin =";Bminm
1360  PRINT "YIELD STRENGTH =";Ysm;"  ULTIMATE TS =";Utsm
1370  PRINT "ELASTIC MODULUS =";Em;"  FLOW STRESS =";Fsm
1380  PRINT ""
1390  PRINTER IS 1                     ! TOGGLES PRINTER TO CRT
1400  !
1410  PRINT CHR$(12)                   ! CLEAR CRT
1420  !
1430  Flag3=0
1440  A1=A
1450  GOSUB Params
1460  !
1470  RETURN
1480  !
1490  !*******************************************
1500  !
1510 New_a:      ! THIS ROUTINE COMPUTES NEW CRACK LENGTH AND NEW PARAMETERS
1520  !
1530  Beffm=Bmaxm-(Bmaxm-Bminm)^2/Bmaxm     ! B EFFECTIVE FROM ASTM E813-81
1540  D2=1               ! INITIALIZES COUNTER
1550  PRINT CHR$(12)    ! CLEARS CRT
1560  PRINT "THIS ROUTINE WILL OBTAIN CURRENT CRACK LENGTH"
1570  PRINT " AND NEW PARAMETERS FOR PRECRACKING."
1580  PRINT "BEFORE YOU CAN RUN THIS ROUTINE YOU MUST:"
1590  PRINT "    1. ENTER SPECIMEN DATA"
1600  PRINT "    2. ENTER CONVERSION DATA"
1610  PRINT "    3. SETUP MTS FOR MANUAL LOADING OF THE";
1620  PRINT "                SPECIMEN."
1630  PRINT " "
1640  PRINT "  ARE YOU READY?"
1650  INPUT H$
1660  IF H$="N" OR H$="NO" THEN 2450  ! RETURNS TO k-KEY SELECTION
1670  PRINT CHR$(12)         ! CLEARS CRT
1680  PRINT "YOU MAY LOAD AND UNLOAD SPECIMEN AS OFTEN AS  YOU LIKE -- BUT YOU M
UST REMAIN ";
1690  PRINT "BELOW CURRENT PMAX OF";Pmax;"Lbs"
1700  DIM Lod(2000),Defl(2000),Cod(2000)
1710  DIM Lodm(2000),Deflm(2000),Codm(2000)
1720  PRINT "WHEN YOU ARE READY TO BEGIN PRESS THE 'ENTER' OR 'CONTINUE' KEY."
1730  INPUT H$
1740  PRINT CHR$(12)           ! CLEARS CRT
```

```
1750  K=0                         ! USED AS COUNTER
1760  I=1                         ! USED AS INDEX
1770  Flag1=0
1780  Flag2=0
1790     WHILE Flag1=0    ! ESTABLISHES ONE LOAD-UNLOAD DATA TAKING LOOP
1800        GOSUB Data_acq
1810     END WHILE
1820     Flag2=0          ! RESETS FLAG2
1830     WHILE Flag2=0
1840        GOSUB Data_acq
1850     END WHILE
1860  !
1870  ! THIS SECTION CAN BE USED TO VIEW THE COLLECTED DATA BY REMOVING THE REMA
RK CHARACTER (!).
1880  ! FOR I=1 TO K
1890    ! PRINT USING 1960;I,Lodm(I),Deflm(I),Codm(I)
1900    ! IMAGE X,3D,4X,6D.D,4X,3D.7D,7X,3D.7D
1910  ! NEXT I
1920  ! WAIT 5
1930  K1=1
1940  K3=K
1950  GOSUB Slope          ! SLOPE = 1/COD COMPLIANCE
1960  GOSUB Crack_length  ! USES COD COMPLIANCE
1970  !
1980  A0(D2)=Crack1m/25.4    ! CONVERTS TO INCHES
1990  A1=A0(D2)
2000  !
2010  ! FIND 95% CONFIDENCE INTERVAL FOR CRACK LENGTH
2020    Stiffm=Stiffm+T9*U4
2030    GOSUB Crack_length
2040    Amax=Crack1m/25.4       ! CONVERTS TO INCHES
2050    Stiffm=Stiffm-2*T9*U4
2060    GOSUB Crack_length
2070    Amin=Crack1m/25.4       ! CONVERTS TO INCHES
2080  !
2090  !
2100  PRINT CHR$(12)       ! CLEARS CRT
2110  PRINT "THE FOLLOWING INFORMATION HAS BEEN OBTAINED:"
2120  PRINT ""
2130  PRINT "CRACK LENGTH =";A0(D2);"in      FROM MEASUREMENT #";D2
2140  PRINT "WITH 95% CONFIDENCE INTERVAL FROM";Amin;" TO";Amax
2150  PRINT ""
2160  PRINT "USING COD COMPLIANCE OF:";Compl;"in/Lb    =";Complm;"mm/N"
2170  PRINT "WITH A CORRELATION OF:";Correl;" FROM";K;"DATA POINTS"
2180  PRINT ""
2190  PRINT "DO YOU WANT A HARD COPY?"
2200  INPUT G$
2210  IF G$="N" OR G$="NO" THEN 2340
2220  !
2230  PRINTER IS 706         ! TOGGLES TO THERMAL PRINTER
2240  PRINT ""
2250  PRINT "THE FOLLOWING INFORMATION HAS BEEN OBTAINED:"
2260  PRINT "CRACK LENGTH =";A0(D2);"in FROM MEASUREMENT #";D2
2270  PRINT "WITH 95%CONFIDENCE INTERVAL FROM";Amin;" TO";Amax;"in"
2280  PRINT "USING COD COMPLIANCE OF:";Compl;"in/Lb =";Complm;"mm/N"
2290  PRINT "WITH A CORRELATION OF:";Correl;"FROM";K;" DATA POINTS."
2300  PRINT ""
2310  PRINTER IS 1          ! TOGGLES PRINTER TO CRT
2320  !
```

```
2330  PRINT ""
2340  PRINT "   DO YOU WANT ANOTHER MEASUREMENT?"
2350  INPUT F$
2360  D2=D2+1       ! INCREMENTS COUNTER
2370  IF F$="Y" OR F$="YES" THEN 1670
2380  !
2390  IF A0(D2-1)>Opta THEN GOSUB End_precrack  ! PRECRACKING IS COMPLETE
2400  !
2410  IF A0(D2-1)>.4*Dela+A THEN Flag3=1    ! SETS FLAG INDICATING IN LAST 60% O
F PRECRACKING
2420  !
2430  GOSUB Params
2440  !
2450  RETURN
2460  !
2470  !*********************************************
2480  !
2490 Data_acq:   ! DATA ACQUISITION ROUTINE
2500   OUTPUT Dvm;"VR5 AF1 AL3"
2510   !
2520   OUTPUT Dvm;"AI1 VT1"        ! READS LOAD
2530   ENTER Dvm;Lod(I)
2540   Lodm(I)=Lod(I)*Slm(1)
2550   !
2560   OUTPUT Dvm;"AI2 VT1"        ! READS COD
2570   ENTER Dvm;Cod(I)
2580   Codm(I)=Cod(I)*Slm(2)
2590   !
2600   OUTPUT Dvm;"AI3 VT1"        ! READS DEFLECTION
2610   ENTER Dvm;Defl(I)
2620   Deflm(I)=Defl(I)*Slm(3)
2630   !
2640   ! TEST  DATA TO BREAK OUT OF DATA ACQ LOOP
2650   !
2660   IF I=1 THEN 2720      ! SKIPS IF FIRST DATA POINT
2670   Lodiffm=Lodm(I)-Lodm(I-1)
2680      IF Lodiffm<-25.0 THEN Flag1=1     ! MUST BE UNLOADING
2690      IF Lodiffm>25.0 THEN Flag2=1      ! MUST BE RELOADING.
2700   Lodiffm=0
2710   !
2720   I=I+1      ! INCREMENTS INDEX
2730   !
2740   K=K+1      ! INCREMENT COUNTER
2750   !
2760   RETURN
2770   !
2780   !*********************************************
2790   !
2800 Crack_length:   ! CALCULATES CRACK LENGTH USING HUDAK (DTNSRDC PROG)
2810   !  NOTE: THIS ROUTINE USES COD COMPLIANCE  METHOD VICE DEFLECTION COMPLIA
NCE.
2820   FOR I=1 TO 6
2830      READ Coef(I)
2840   NEXT I
2850   Complm=1/Stiffm
2860   C=2*Wm*Beffm*Em*Complm/(Hsm*1000)
2870   C=1/(SQR(C)+1)
2880   G(1)=C
2890   FOR I=2 TO 5
2900      G(I)=G(I-1)*G(1)
```

```
2910    NEXT I
2920    F=Coef(1)
2930    FOR I=1 TO 5
2940       F=F+Coef(I+1)*G(I)
2950    NEXT I
2960    Crack lm=F*Wm
2970    RESTORE
2980    DATA 0.998265,-3.81662,-1.80596,32.31038,-44.15665.-52.67876
2990    !
3000    RETURN
3010    !
3020    !****************************************
3030    !
3040 Conv_data:     ! INPUTS CONVERSION DATA FOR MEASURING DEVICES
3050    PRINT CHR$(12)            ! CLEARS CRT
3060    PRINT "INPUT: LOAD RANGE, STRAIN RANGE, STROKE RANGE"
3070    PRINT ""
3080    PRINT "    (BY PERCENT ie. 10,20,50 OR 100)"
3090     INPUT Lr,Cr,Sr
3100    PRINT ""
3110    PRINT "LOAD RANGE = ";Lr
3120    PRINT "STRAIN (COD) RANGE = ";Cr
3130    PRINT "STROKE (DEFLECTION) RANGE = ";Sr
3140    Lmax=20000      ! MAX LOAD RANGE IN (lbs).
3150    Cmax=.200       ! MAX COD RANGE IN (in).
3160    Smax=5.0        ! MAX STROKE RANGE IN (in).
3170    V=-10            ! MAX VOLTAGE IN (volts).
3180    !
3190    ! MAXIMUM OPERATING POINTS ARE:
3200    Olmax=Lmax*Lr/100
3210    Ocmax=Cmax*Cr/100*(-1.0)  ! -1 CHANGES SIGN
3220    Osmax=Smax*Sr/100
3230    !
3240    ! CONVERSION CONSTANTS ARE: (ENGLISH UNITS)
3250    Sl(1)=Olmax/V
3260    Sl(2)=Ocmax/V
3270    Sl(3)=Osmax/V
3280    ! CONVERTING TO METRIC:
3290    Conlen=25.4               ! 25.4mm = 1in
3300    Conlb=4.448221615        ! 4.448221615N = 1lb      (HP PROGRAMING BOOK)
3310    Slm(1)=Sl(1)*Conlb
3320    Slm(2)=Sl(2)*Conlen
3330    Slm(3)=Sl(3)*Conlen
3340    !
3350    PRINT ""
3360    PRINT ""
3370    PRINT "YOUR ENTRIES HAVE PRODUCED THE FOLLOWING           CONVERSION DATA:
"
3380    PRINT ""
3390    PRINT "FOR LOAD: ";Slm(1);"NEWTON/VOLT   (";Sl(1);"Lbs/V)"
3400    PRINT ""
3410    PRINT "FOR COD: ";Slm(2);"mm/V   (";Sl(2);"in/V)"
3420    PRINT ""
3430    PRINT "FOR DEFLECTION: ";Slm(3);"mm/V (";Sl(3);"in/V)"
3440    PRINT ""
3450    PRINT "WOULD YOU LIKE A HARD COPY?"
3460    INPUT H$
3470    IF H$="N" OR H$="NO" THEN 3570
3480    !
3490    PRINTER IS 706            ! TOGGLES PRINTER
```

```
3500   PRINT ""
3510   PRINT "        CONVERSION DATA"
3520   PRINT "FOR LOAD:";Slm(1):"N/V    (";Sl(1);"Lbs/V)"
3530   PRINT "FOR COD:";Slm(2):"mm/V    (";Sl(2);"in/V)"
3540   PRINT "FOR DEFLECTION:";Slm(3):"mm/V   (";Sl(3);"in/V)"
3550   PRINTER IS 1              ! TOGGLES PRINTER
3560   !
3570   PRINT CHR$(12)
3580   !
3590   RETURN
3600   !
3610   !********************************************
3620   !
3630 Slope:    ! LINEAR LEAST SQUARES FIT
3640   PRINT CHR$(12)         ! CLEAR CRT
3650   ! INITIALIZE VARIABLES
3660   Sumx=0      ! SUM OF X VALUES
3670   Sumx2=0     ! SUM OF X SQUARED VALUES
3680   Sumy=0      ! SUM OF Y VALUES
3690   Sumy2=0     ! SUM OF Y SQUARED VALUES
3700   Sumxy=0     ! SUM OF THE PRODUCT
3710   FOR I=K1 TO K3     ! K1=INDEX OF FIRST, K3=INDEX OF LAST DATA POINT USED.
3720      !
3730      X=Codm(I)
3740      Y=Lodm(I)
3750      !
3760      Sumx=Sumx+X
3770      Sumy=Sumy+Y
3780      Sumx2=Sumx2+X*X
3790      Sumy2=Sumy2+Y*Y
3800      Sumxy=Sumxy+X*Y
3810   NEXT I
3820   K3=K3-P2       ! USED TO CALCULATE NUMBER OF DATA POINTS WITHIN BOUNDS.
3830   K4=K3-K1+1         ! K4=TOTAL # DATA POINTS USED IN CALC
3840   Qa1=Sumx2-Sumx*Sumx/K4
3850   Qa2=Sumxy-Sumx*Sumy/K4
3860   Qa3=Sumy2-Sumy*Sumy/K4
3870   !
3880   M=Qa2/Qa1              ! SLOPE
3890   !
3900   IF M<0 THEN 4190   ! IF SLOPE < 0, BAD DATA
3910   !  FROM DTNSRDC PROGRAM
3920   Q1=(K4*Sumx2-Sumx^2)/(K4*(K4-1))
3930   Q2=(K4*Sumy2-Sumy^2)/(K4*(K4-1))
3940   Q3=(K4-1)*(Q2-M*M*Q1)/(K4-2)
3950   Q4=SQR(Q3/(Q1*(K4-1)))
3960   !
3970   B=(Sumy-M*Sumx)/K4      ! INTERCEPT
3980   !
3990   Correl=M*SQR(Q1/Q2)
4000   !
4010   Qa4=SQR(ABS((Sumy2-B*Sumy-M*Sumxy)/(K4-2)))
4020   Sigmab=Qa4/SQR(ABS(Qa1))
4030   Sigmam=Sigmab*SQR(Sumx2/K4)
4040   Stiffm=M                      ! STIFF = SLOPE
4050   Complm=1/M        ! COD COMPLIANCE = 1/SLOPE
4060   Compl=Complm*(4.448221615)/25.4  ! CONVERTS TO  in/LB
4070   !
4080   ! STUDENT t TEST
4090   U4=Q4
```

```
4100    T9=1.96
4110    IF K4>120 THEN 4170             ! RETURNS
4120    T9=2.1
4130    IF K4<20 THEN 4170              ! RETURNS
4140    N9=K4-2
4150    T9=N9/(-.617109+N9*.510239)
4160    !
4170    RETURN
4180    !
4190    PRINT "POOR DATA-- SLOPE < 0"
4200    M=333333.3
4210    Correl=0
4220    !
4230    RETURN
4240    !
4250    !********************************************
4260    !
4270 Params:      ! THIS ROUTINE WILL DETERMINE THE CURRENT MAX AND MIN LOAD FOR
FATIGUE PRECRACKING
4280    !
4290    ! NOTE THE USE OF ENGLISH UNITS DUE MTS READOUT BEING IN POUNDS.
4300    ! INITIALIZE VARIABLES
4310    Faw=0
4320    Pmax=0
4330    Pmin=0
4340    Delp=0
4350    Kmaxp=0
4360    Kminp=0
4370    Delk=0
4380    Delke=0
4390    !
4400    Opta=.6*W      ! OPTIMUM CRACK LENGTH
4410    Dela=Opta-Al   ! EXTENSION REQUIRED
4420    Dela50=Dela*(.5)+A   ! CRACK LENGTH AT 50% OF EXTENSION
4430    !
4440    Pmax=(4/3)*(Bmin*(W-Al)^2*Fs/(2*Hs))   ! FROM ASTM E813
4450    IF Flag3=1 THEN Pmax=(.4)*Pmax         ! MAX LOAD DURING LAST 50% OF PRECR
ACKING (ASTM E813)
4460    Pmin=Pmax-.95*Pmax       ! FROM ASTM E813
4470    Delp=Pmax-Pmin
4480    !
4490    ! DETERMINE Delk BASED ON P USING ASTM E399
4500    !
4510    Fawn=3*(Al/W)^.5*(1.99-(Al/W)*(1-Al/W)*(2.15-3.93*Al/W+2.7*(Al/W)^2))
4520    !
4530    Fawd=2*(1+2*Al/W)*(1-Al/W)^1.5
4540    !
4550    Faw=Fawn/Fawd
4560    !
4570    !
4580    Kmaxp=(Pmax*2*Hs/(Bmin*W^1.5))*Faw     ! FROM ASTM E399
4590    Kminp=(Pmin*2*Hs/(Bmin*W^1.5))*Faw     ! FROM ASTM E399
4600    Delk=Kmaxp-Kminp
4610    !
4620    ! DETERMINE Delke BASED ON MODULUS FROM ASTM E813
4630    IF Flag3=0 THEN Delke=40000          ! DURING EARLY EXTENSION
4640    IF Flag3=1 THEN Delke=(.001)*E       ! DURING LAST 50% OF PRECRACKING  [RE
F. ASTM E399 & E813]
4650    PRINT ""
```

```
4660    PRINT "BASED ON CURRENT INFORMATION:"
4670    PRINT ""
4680    PRINT "CURRENT CRACK LENGTH =";A1;"in"
4690    PRINT "OPTIMUM a0=";Opta:"in"
4700    PRINT "EXTENSION REQUIRED =";Dela
4710    PRINT "CRACK LENGTH AT 50% OF EXTENSION =";Dela50;"in"
4720    PRINT "Pmax =";Pmax:"Lbs  Pmin =";Pmin:"Lbs"
4730    PRINT "Kmaxp =";Kmaxp:"   Kminp =";Kminp
4740    PRINT "DELTA_K =";Delk:"in^.5"
4750    PRINT "DELTA_KE =";Delke:"in^.5"
4760    PRINT "FAW =";Faw       ! SERVES AS A CHECK
4770    PRINT ""
4780    PRINT "IF Delk > Delke. Pmax MUST BE DECREASED"
4790    IF Delk<Delke THEN 4900      ! SKIP IF OKAY
4800    ! COMPUTE NEW Pmax
4810    Delp1=(Delke/Faw/(2*Hs)*Bmin*W^1.5)
4820    Pmax1=Delp1/.95
4830    Pmin1=Pmax1-.95*Pmax1
4840    Kmax1=(Pmax1*2*Hs/(Bmin*W^1.5))*Faw
4850    PRINT "THE NEW Pmax BASED ON Delke IS:";Pmax1;"Lbs"
4860    PRINT "NEW Pmin =";Pmin1;"Lbs"
4870    PRINT "NEW DELTA_P =";Delp1;"Lbs"
4880    PRINT "NEW Kmax =";Kmax1
4890    !
4900    PRINT "   DO YOU WANT A HARD COPY?"
4910    INPUT H$
4920    IF H$="N" OR H$="NO" THEN 5080
4930    PRINTER IS 706        ! TOGGLES PRINTER
4940    PRINT "BASED ON CURRENT INFORMATION FOR ";D$;":"
4950    PRINT ""
4960    PRINT "CURRENT CRACK LENGTH =";A1;"in"
4970    PRINT "OPTIMUN CRACK LENGTH =";Opta:"in"
4980    PRINT "EXTENSION REQUIRED =";Dela:"in"
4990    PRINT "CRACK LENGTH AT 50% OF EXTENSION =";Dela50;"in"
5000    PRINT "Pmax =";Pmax:"Lbs  Pmin =";Pmin;"Lbs"
5010    PRINT "Delp =";Delp:"Lbs  Kmax =";Kmaxp
5020    PRINT "DELTA_K =";Delk:"in^.5  DELTA_KE =";Delke;"in^.5"
5030    IF Delk<Delke THEN 5090
5040    PRINT ""
5050    PRINT "NEW LOADS  BASED ON DELTA_KE ARE:"
5060    PRINT "Pmax =";Pmax1;"Lbs  Pmin =";Pmin1;"Lbs"
5070    PRINT "DELTA_P =";Delp1;"Lbs   Kmax =";Kmax1
5080    PRINT ""
5090    PRINTER IS 1       ! TOGGLES PRINTER TO CRT
5100    PRINT ""
5110    PRINT "MAKE THE NECESSARY ADJUSTMENTS BEFORE CONTINUING."
5120    PRINT "WHEN COMPLETED PRESS 'CONTINUE'."
5130    INPUT C$
5140    !
5150    RETURN
5160    !
5170    !******************************************
5180    !
5190 A_table:        ! PRODUCES TABULATED VALUES FOR LOAD vs COD VALUES AT VARIOU
S CRACK LENGTHS
5200    !
5210    PRINT "BEFORE YOU CAN RUN THIS SUBROUTINE YOU MUST ENTER:"
5220    PRINT "       1.  SPECIMEN DATA"
5230    PRINT "       2.  CONVERSION DATA"
```

```
5240    PRINT ""
5250    PRINT "ARE YOU READY?"
5260    INPUT H$
5270    IF H$="N" OR H$="NO" THEN 5550    ! RETURNS TO k-KEY SELCETION
5280    !
5290    Beff=Bmax-(Bmax-Bmin)^2/Bmax       ! IAW ASTM E813-81
5300    PRINT "BEFF =";Beff
5310    !
5320    ! USING CRACK LENGTH EQUATION FROM DTNSRDC PROGRAM CALC CRACK LENGTH FOR
VARIOUS VALUES OF U
5330    A00=.998265
5340    A1=-3.81662
5350    A2=-1.80596
5360    A3=32.31038
5370    A4=-44.15665
5380    A5=-52.67876
5390    FOR U=.07 TO .155 STEP .005
5400       Ar=A00+A1*U+A2*U^2+A3*U^3+A4*U^4+A5*U^5
5410       Ckl=Ar*W
5420       PRINTER IS 706     ! TOGGLES TO THERMAL PRINTER
5430       PRINT "U =";U
5440       PRINT "a/W =";Ar;"in  CRACK LENGTH =";Ckl;"in"
5450       PRINT "LOAD (lbs)       COD (in)        COD (Volts)"
5460       FOR Lod1=200 TO 1800 STEP 100
5470          C=Beff*W*E*2/Hs
5480          Cod1=Lod1*((1-U)/U)^2/C
5490          Codv=Cod1/S1(2)
5500          PRINT Lod1,Cod1,Codv
5510       NEXT Lod1
5520    NEXT U
5530    PRINTER IS 1      ! RETURNS TO USING CRT AS PRINTER
5540    !
5550    RETURN
5560    !
5570    !***************************************
5580    !
5590 End_precrack:          ! END OF PRECRACKING
5600    !
5610    PRINT "     PRECRACKING IS COMPLETED!"
5620    PRINT ""
5630    PRINT "FINAL CRACK LENGTH =";A0(D2-1)
5640    PRINT "CORRELATION OF DATA =";Correl
5650    PRINT ""
5660    PRINT "    REMOVE SPECIMEN FROM MTS."
5670    !
5680    END
```

APPENDIX E

J_INTGL LISTING

```
10     ! J-INTEGRAL FRACTURE TOUGHNESS PROGRAM
20     ! FOR THREE POINT BEND SPECIMEN.  THIS
30     ! PROGRAM INCORPORATES THE USE OF THE
40     ! FOLLOWING EQUIPTMENT:
50     !      1. HP-9826 COMPUTER
60     !      2. HP-3497A DATA ACQUISITION SYSTEM
70     !      3. HP-3437A SYSTEM VOLTMETER
80     !      4. HP-2671G THERMAL PRINTER
90     !      5. HP-7225B PLOTTER
100    !
110    ! THIS PROGRAM WAS WRITTEN BY:
120    !      LCDR W. K. TRITCHLER, USN
130    ! VERSION 1.0     DATE 11/83
140    !
150    !
160    !
170    COM /J_intgl/ F1
180    !
190    ! DIM Lod(8000),Defl(8000),Cod(8000)
200    ! NOTE: Lod, Defl AND Cod ARE ACTUALLY DIMENSIONED IN Initial_a ROUTINE
210    ! Lod(I) = LOAD
220    ! Defl(I) = DEFLECTION
230    ! Cod(I) = CRACK OPENING DISPLACEMENT (COD)
240    !
250    DIM A0(50),Amin0(50),Amax0(50),Compl0(50),Correl0(50)
260    DIM Area9(100),A1(100),Coef(6),G(6)
270    DIM J9(100),Delta_a(100),Mdefl(100)
280    DIM Data$(1:4)[10]
290    DUMP DEVICE IS 706     ! THERMAL PRINTER ADDRESS
300    Dvm=709                ! DATA ACQUISITION ADDRESS
310    CLEAR Dvm
320    PRINT CHR$(12)        ! CLEARS CRT
330    PRINT ""
340    PRINT "             J-INTEGRAL TEST PROGRAM"
350    PRINT "                  VERSION 1.0"
360    PRINT "           WRITTEN BY LCDR W.K. TRITCHLER"
370    PRINT ""
380    PRINT "              PLEASE SELECT A k-KEY"
390    !
400    !*******************************************
410 Begin: !
420    ON KEY 0 LABEL "SPEC_DATA" GOSUB Spec_data
430    ON KEY 1 LABEL "CONV_DATA" GOSUB Conv_data
440    ON KEY 2 LABEL "DAT_FILE" GOSUB Data_file
450    ON KEY 3 LABEL "PLOTTER" GOSUB Setup_plotter
460    ON KEY 4 LABEL "GCLEAR" GOSUB Gclr
470    ON KEY 5 LABEL "a0" GOSUB Initial_a
480    ON KEY 7 LABEL "START" GOSUB Main_prog
490    !(*) ON KEY 8 LABEL "R-CURVE" GOSUB R_curve
500    ! (SEE NOTES ON (*) IN R_curve ROUTINE
510    ON KEY 9,4 CALL Stop_test
520    !
530    !*******************************************
540    !
550 Spin:     ! WAITS FOR KEY INPUT
560    GOTO Spin
570    !
580    !*******************************************
590    !
```

```
600 Gclr:      ! GRAPHICS SCREEN CLEAR
610    ! THIS ROUTINE ALLOWS SINGLE KEY STROKE TO REMOVE A GRAPHICS DISPLAY FROM
CRT
620    GCLEAR
630    RETURN  ! RETURNS TO k-KEY SELECTION
640    !
650    !*******************************************
660    !
670 Spec_data:   ! INPUTS REQUIRED SPECIMEN DATA
680    PRINT CHR$(12)        ! CLEARS CRT
690    PRINT "INPUT SPECIMEN IDENTIFICATION (ID):"
700    INPUT D$
710    PRINT ""
720    PRINT "J-INTEGRAL TEST for ";D$
730    PRINT ""
740    PRINT "INPUT SPECIMEN DATA USING ENGLISH UNITS (LBS.      INCHES, etc.)"
750    PRINT ""
760    PRINT "WHAT IS THE SPECIMEN'S WIDTH, NOTCH LENGTH, Bmax,  Bmin (THICKNESS)
?"
770    INPUT W,A,Bmax,Bmin
780    PRINT ""
790    PRINT "WHAT IS THE SPECIMEN'S HALF SPAN AND POISSON'S     RATIO?"
800    INPUT Hs,Nu
810    PRINT ""
820    PRINT "WHAT IS THE SPECIMEN'S ELASTIC MODULUS, YIELD      STRENGTH AND ULT
IMATE STRENGTH?"
830    INPUT E,Ys,Uts
840    PRINT CHR$(12)              ! CLEARS CRT
850    Fs=(Ys+Uts)/2
860    PRINT "USING ENGLISH UNITS (in,lbs,psi)"
870    PRINT "THE FOLLOWING HAS BEEN ENTERED for: ";D$
880    PRINT "WIDTH =";W:"    NOTCH LENGTH =";A
890    PRINT "Bmax =";Bmax:"          Bmin =";Bmin
900    PRINT "HALF SPAN =":Hs:"   POISSON'S RATIO =";Nu
910    PRINT "YIELD STRENGTH =";Ys:"  ULTIMATE TS =":Uts
920    PRINT "ELASTIC MODULUS =";E:"   FLOW STRESS =";Fs
930    PRINT ""
940    PRINT "THIS PROGRAM ALLOWS NO EASY RECOVERY, IF ANY DATA IS INCORRECT YOU
MUST RE-ENTER ":
950    PRINT "EVERYTHING."
960    PRINT ""
970    PRINT "IS ALL DATA CORRECT?"
980    INPUT H$
990    IF H$="NO" OR H$="N" THEN 670   ! REPEATS Spec_data
1000   PRINT ""
1010   PRINT "DO YOU WANT A HARD COPY?"
1020   INPUT H$
1030   IF H$="N" OR H$="N" THEN 1180
1040   !
1050   PRINTER IS 706           ! TOGGLES PRINTER TO THERMAL PRINTER
1060   PRINT ""
1070   PRINT "USING ENGLISH UNITS (in,lbs,psi) THE FOLLOWING INFORMATION"
1080   PRINT "HAS BEEN ENTERED FOR: ";D$
1090   PRINT ""
1100   PRINT "WIDTH =";W:"       NOTCH LENGTH =";A
1110   PRINT "Bmax =";Bmax;"       Bmin =";Bmin
1120   PRINT "HALF SPAN =":Hs;" POISSON'S RATIO =";Nu
1130   PRINT "YIELD STRENGTH =";Ys:" ULTIMATE TS =";Uts
1140   PRINT "ELASTIC MODULUS =";E:" FLOW STRESS =";Fs
1150   PRINT ""
```

```
1160  PRINTER IS 1          ! TOGGLES PRINTER BACK TO CRT
1170  !
1180  PRINT CHR$(12)       ! CLEARS CRT
1190  !
1200  ! CONVERSION TO METRIC UNITS
1210  Conlen=25.4              ! 1in = 25.40mm
1220  W=W*Conlen
1230  A=A*Conlen
1240  Bmax=Bmax*Conlen
1250  Bmin=Bmin*Conlen
1260  Hs=Hs*Conlen
1270  Conpress=6.89475293       ! 1psi = 6.89475293kPa (HP PROGRAMING BOOK)
1280  E=E*Conpress
1290  Ys=Ys*Conpress
1300  Uts=Uts*Conpress
1310  Fs=Fs*Conpress
1320  !
1330  PRINT "CONVERTING THIS DATA TO METRIC UNITS (mm,N,KPa)      for ";D$;" YIEL
DS:"
1340  PRINT "WIDTH =";W;"    NOTCH LENGTH =";A
1350  PRINT "Bmax =";Bmax;"        Bmin =";Bmin
1360  PRINT "HALF SPAN =";Hs;"    POISSON'S RATIO =";Nu
1370  PRINT "YIELD STRENGTH =";Ys;"  UTILMATE TS =";Uts
1380  PRINT "ELASTIC MODULUS =";E;"  FLOW STRESS =";Fs
1390  PRINT ""
1400  PRINT "DO YOU WISH TO HAVE A PRINT OUT OF THIS DATA?"
1410  INPUT G$
1420  IF G$="N" OR G$="NO" THEN 1540
1430  !
1440  PRINTER IS 706              ! TOGGLES TO THERMAL PRINTER
1450  PRINT "CONVERTING THIS DATA TO METRIC UNITS (mm,N,KPa) FOR: ";D$
1460  PRINT "WIDTH =";W;"       NOTCH LENGTH =";A
1470  PRINT "Bmax =";Bmax;"    Bmin =";Bmin
1480  PRINT "HALF SPAN =";Hs;"    POISSON'S RATIO =";Nu
1490  PRINT "YIELD STRENGTH =";Ys;"  ULTIMATE TS =";Uts
1500  PRINT "ELASTIC MODULUS =";E;"  FLOW STRESS =";Fs
1510  PRINT ""
1520  PRINTER IS 1                    ! TOGGLES PRINTER TO CRT
1530  !
1540  PRINT CHR$(12)                  ! CLEAR CRT
1550  !
1560  RETURN        ! RETURNS TO k-KEY SELECTION
1570  !
1580  !****************************************
1590  !
1600 Setup_plotter: ! SET UP INTERACTIVE PLOTTER
1610  ! YOU CAN CHOOSE BETWEEN THREE DIFFERENT PLOTS
1620  ! (P vs COD, P vs DEFLECTION, OR J vs DELTA_A)
1630  PRINT CHR$(12)               ! CLEARS CRT
1640  DIM T$[80],X$[80],Y$[80]
1650  GCLEAR
1660  GINIT
1670  GRAPHICS ON
1680  PLOTTER IS 3,"INTERNAL"        ! PLOTS ON CRT FOR VIEWING BEFORE SENDING TO
 HP-7225B PLOTTER
1690  PRINT "TYPE OF PLOT:"
1700  PRINT "    1. LOAD vs COD"
1710  PRINT "    2. LOAD vs DEFLECTION"
1720  PRINT "    3. J vs CRACK EXTENSION"
1730  PRINT "ENTER THE # OF THE PLOT YOU DESIRE"
```

```
1740  INPUT C2
1750  PRINT ""
1760  PRINT ""
1770  IF C2=1 THEN 1810
1780  IF C2=2 THEN 1860
1790  IF C2=3 THEN 1910
1800  PRINT ""
1810  T$="PLOT of LOAD vs COD for "&D$
1820  PRINT T$
1830  X$="COD (mm)"
1840  Y$="LOAD (N)"
1850  GOTO 1950
1860  T$="PLOT of LOAD vs DEFLECTION for "&D$
1870  PRINT T$
1880  X$="DEFLECTION (mm)"
1890  Y$="LOAD (N)"
1900  GOTO 1950
1910  T$="PLOT of J vs CRACK EXTENSION for "&D$
1920  PRINT T$
1930  X$="DELTA_a  (mm)"
1940  Y$="J  (kJ/m^2)"
1950  PRINT ""
1960  PRINT "USING METRIC UNITS (mm,N,kJ/m`2,etc):"
1970  PRINT "ENTER HERE THE Xmin,Xmax.Ymin.Ymax"
1980   INPUT X1(C2),X2(C2).Y1(C2).Y2(C2)
1990  X3=X2(C2)-X1(C2)
2000  Y3=Y2(C2)-Y1(C2)
2010  VIEWPORT 13.100*RATIO.10,90
2020  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
2030  PRINT ""
2040  PRINT "INPUT DELTA_X AND DELTA_Y LABEL INTERVAL"
2050  PRINT "FOR THE TWO AXES:"
2060   INPUT X4,Y4
2070  PRINT ""
2080  PRINT "DO YOU WISH TO HAVE A GRID OVERLAY?"
2090  INPUT G$
2100  IF G$="NO" OR G$="N" THEN 2140
2110  PRINT ""
2120  PRINT "INPUT GRID LINES PER DELTA LABEL:"
2130  INPUT B0
2140  PRINT "PRESS 'ENTER' TO PLOT"
2150  INPUT H$
2160  PRINT CHR$(12)     ! CLEARS CRT <------------
2170  IF G$="NO" OR G$="N" THEN 2310
2180  FOR I=X4/B0+X1(C2) TO X2(C2) STEP X4/B0
2190     MOVE I,Y1(C2)
2200     DRAW I,Y2(C2)
2210  NEXT I
2220  FOR I=Y4/B0+Y1(C2) TO Y2(C2) STEP Y4/B0
2230     MOVE X1(C2),I
2240     DRAW X2(C2),I
2250  NEXT I
2260  GOTO 2320
2270  IF G$="Y" OR G$="YES" THEN 2320
2280  MOVE X2(C2),Y1(C2)
2290  DRAW X2(C2),Y2(C2)
2300  DRAW X1(C2),Y2(C2)
2310  CLIP ON
2320  AXES X4,Y4,X1(C2),Y1(C2)
2330  CLIP OFF
```

```
2340  VIEWPORT 13.100*RATIO.5,90
2350  WINDOW X1(C2).X2(C2),Y1(C2),Y2(C2)
2360  LORG 4
2370  CSIZE 3..6          ! LABELS X DIGITS
2380  FOR X=X1(C2) TO X2(C2) STEP X4
2390     CLIP OFF
2400     MOVE X.Y1(C2)
2410     CLIP OFF
2420     LABEL USING "K";X
2430  NEXT X
2440  VIEWPORT 4.100*RATIO.10,90
2450  WINDOW X1(C2),X2(C2).Y1(C2).Y2(C2)
2460  LORG 2              ! LABELS Y DIGITS
2470  FOR Y=Y1(C2) TO Y2(C2) STEP Y4
2480     CLIP OFF
2490     MOVE X1(C2),Y
2500     CLIP OFF
2510     LABEL USING "K";Y
2520  NEXT Y
2530  VIEWPORT 0.RATIO*100,0.100
2540  WINDOW X1(C2).X2(C2).Y1(C2),Y2(C2)
2550  CSIZE 5
2560  LORG 6                ! PLOTS TITLE
2570     MOVE X2(C2)/2,Y2(C2)
2580     LABEL T$
2590  DEG
2600  LDIR 90
2610  CSIZE 4..7
2620     MOVE X1(C2),Y2(C2)/2
2630     LABEL Y$           ! PLOTS Y-AXIS LABEL
2640  LORG 4
2650  LDIR 0
2660     MOVE X2(C2)/2,Y1(C2)
2670     LABEL X$           ! PLOTS X-AXIS LABEL
2680  !
2690  PRINT ""
2700  PRINT ""
2710  PRINT ""
2720  PRINT ""
2730  PRINT "       IS THE PLOT (AXES AND LABELS) OK?"
2740  PRINT ""
2750  PRINT "             NOTE:  IF YOU ANSWER YES OR Y"
2760  PRINT "                    PLOT WILL BE PRODUCED"
2770  PRINT "                    ON EXTERNAL PLOTTER."
2780  INPUT F$
2790  IF F$="N" OR F$="NO" THEN GOSUB Setup_plotter   ! REDO PLOTTER SETUP
2800  !
2810  GCLEAR               ! CLEARS PLOT FROM CRT
2820  !
2830  GOSUB Ext_plotter    ! SENDS PLOT TO PLOTTER
2840  !
2850  PENUP
2860  MOVE 0,0
2870  !
2880  RETURN           ! RETURNS TO k-KEY SELECTION OR R_curve ROUTINE
2890  !
2900  !*****************************************
2910  !
2920 Ext_plotter:  ! DUMPS PLOTTER SETUP TO EXTERNAL HP-7225B PLOTTER
2930  !
```

```
2940   PLOTTER IS 705."HPGL"
2950   VIEWPORT 13.100*RATIO.10.90
2960   WINDOW X1(C2).X2(C2).Y1(C2).Y2(C2)
2970   IF G$="NO" OR G$="N" THEN 3080
2980   FOR I=X4/80+X1(C2) TO X2(C2) STEP X4/80
2990      MOVE I,Y1(C2)
3000      DRAW I.Y2(C2)
3010   NEXT I
3020   FOR I=Y4/80+Y1(C2) TO Y2(C2) STEP Y4/80
3030      MOVE X1(C2),I
3040      DRAW X2(C2),I
3050   NEXT I
3060   GOTO 3120
3070   IF G$="Y" OR G$="YES" THEN 3120
3080   MOVE X2(C2),Y1(C2)
3090   DRAW X2(C2).Y2(C2)
3100   DRAW X1(C2),Y2(C2)
3110   CLIP ON
3120   AXES X4.Y4.X1(C2),Y1(C2)
3130   CLIP OFF
3140   VIEWPORT 13.100*RATIO.5.90
3150   WINDOW X1(C2).X2(C2),Y1(C2).Y2(C2)
3160   LORG 4
3170   CSIZE 3,.6              ! SIZE OF DIGITS
3180   FOR X=X1(C2) TO X2(C2) STEP X4
3190      CLIP OFF
3200      MOVE X.Y1(C2)
3210      CLIP OFF
3220      LABEL USING "K";X      ! LABELS X-AXIS
3230   NEXT X
3240   VIEWPORT 4.100*RATIO.10.90
3250   WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
3260   LORG 2
3270   FOR Y=Y1(C2) TO Y2(C2) STEP Y4
3280      CLIP OFF
3290      MOVE X1(C2),Y
3300      CLIP OFF
3310      LABEL USING "K";Y      ! LABELS Y-AXIS
3320   NEXT Y
3330   VIEWPORT 0.100*RATIO,0.100
3340   WINDOW X1(C2),X2(C2),Y1(C2).Y2(C2)
3350   CSIZE 5                   ! TITLE SIZE
3360   LORG 6
3370      MOVE X2(C2)/2.Y2(C2)
3380      LABEL T$               ! PRINTS TITLE
3390   DEG
3400   LDIR 90
3410   CSIZE 4,.7
3420      MOVE X1(C2),Y2(C2)/2
3430      LABEL Y$             ! PRINTS Y-AXIS TITLE
3440   LORG 4
3450   LDIR 0
3460      MOVE X2(C2)/2.Y1(C2)
3470      LABEL X$             ! PRINTS X-AXIS TITLE
3480   PENUP
3490   MOVE 0,0
3500   !
3510   RETURN'          ! RETURNS TO Setup_plotter
3520   !
3530   !*********************************************
```

```
3540  !
3550 Initial_a:    ! ESTIMATES INITIAL CRACK LENGTH
3560  Beff=Bmax-(Bmax-Bmin)^2/Bmax      ! USES B(EFFECTIVE) FROM ASTM E813-81
3570  D2=1                        ! INITIALIZES COUNTER
3580  PRINT CHR$(12)              ! CLEARS CRT
3590  PRINT "BEFORE YOU CAN RUN THIS ROUTINE YOU MUST:"
3600  PRINT "       1. ENTER SPECIMEN DATA"
3610  PRINT "       2. ENTER CONVERSION DATA"
3620  PRINT "       3. SET UP PLOTTER"
3630  PRINT "       4. CREATE DATA FILE"
3640  PRINT ""
3650  PRINT "ARE YOU READY?"
3660  INPUT H$
3670  IF H$="N" OR H$="NO" THEN 5070    ! RETURNS TO KEY SELECTION SCREEN
3680  PRINT CHR$(12)                    ! CLEARS CRT
3690  PRINT "THIS ROUTINE WILL OBTAIN THE INITIAL CRACK LENGTH AFTER FATIGUE PRE
-CRACKING."
3700  PRINT ""
3710  PRINT "YOU MAY LOAD AND UNLOAD THE SPECIMEN AS OFTEN AS  YOU LIKE -- BUT Y
OU MUST REMAIN ";
3720  PRINT "ON THE LINEAR      PORTION OF THE CURVE!"
3730  PRINT ""
3740  PRINT "NOTE:  THE MTS SHOULD BE IN 'STROKE' CONTROL"
3750  PRINT "       AT A VERY SLOW INVERTED RAMP FUNCTION"
3760  PRINT "       RATE OR YOU MAY DO THIS WITH MANUAL LOAD"
3770  PRINT "       CONTROL."
3780  PRINT ""
3790  !
3800  PRINT "WOULD YOU LIKE AN ESTIMATE OF Pmax (Lbs)?"
3810  INPUT E$
3820  IF E$="N" OR E$="NO" THEN 4060  ! SKIPS Pmax CALC
3830  !
3840  PRINT "YOU MUST PROVIDE AN ESTIMATE OF CURRENT CRACK      LENGTH"
3850  PRINT "INPUT YOUR ESTIMATE IN INCHES."
3860  INPUT Aest
3870  ! CONVERT ALL DIMENSIONS BACK TO ENGLISH UNITS.
3880  ! a0 IS SUFFIX ON ALL VARIABLES FOR THIS CALC.
3890  Beffa0=Beff/Conlen
3900  Wa0=W/Conlen
3910  Blig=(Wa0-Aest)            ! ESTIMATED LENGTH OF UNBROKEN LIGAMENT IN INCHES
3920  Fsa0=Fs/Conpress
3930  Hsa0=Hs/Conlen
3940  Pla0=.533*Beffa0*Blig^2*Fsa0/(2*Hsa0)
3950  PRINT "AN ESTIMATE OF Pmax IS";Pla0
3960  PRINT "Pmax ESTIMATES THE POINT AT WHICH THE CURVE"
3970  PRINT "BECOMES NONLINEAR, IAW ASTM E813-81"
3980  !
3990  PRINTER IS 706   ! TOGGLES PRINTER
4000  PRINT ""
4010  PRINT "GIVEN a=";Aest;"inches THEN:"
4020  PRINT "   Pmax=";Pla0;"Lbs FROM ASTM E813-81"
4030  PRINT ""
4040  PRINTER IS 1
4050  !
4060  DIM Lod(8000),Defl(8000),Cod(8000)
4070  !
4080  ! ASSIGN DEFL CORRECTION COEF USED IN Data_acq AND Take_data ROUTINES
4090  ! THIS USES A 4th ORDER POLYNOMIAL FIT OF RECORDED DATA ON THE MTS SYSTEM'
S COMPLIANCE
4100  !
```

```
4110  Corr(1)=5.798E-5
4120  Corr(2)=4.7419E-6
4130  Corr(3)=-2.803E-9
4140  Corr(4)=1.471E-12
4150  Corr(5)=-2.7741E-16
4160  !
4170  PRINT ""
4180  PRINT "WHEN YOU ARE READY TO BEGIN PRESS THE 'ENTER' KEY."
4190  INPUT H$
4200  PRINT CHR$(12)       ! CLEARS CRT
4210  K=0           ! USED AS A COUNTER
4220  I=1           ! USED AS INDEX
4230  Flag1=0     ! NOTE: FLAG1 AND FLAG2 ARE RESET
4240  Flag2=0     ! IN Data_acq ROUTINE
4250     WHILE Flag1=0      ! ESTABLISHES ONE LOAD-UNLOAD DATA TAKING LOOP
4260        GOSUB Data_acq
4270     END WHILE
4280     Flag2=0            !  RESETS FLAG2
4290     WHILE Flag2=0
4300        GOSUB Data_acq
4310     END WHILE
4320   PENUP
4330   ! THIS SECTION CAN BE USED TO VIEW THE COLLECTED DATA BY REMOVING THE REM
ARK CHARACTER (!).
4340   ! FOR I=1 TO K
4350      ! PRINT USING 3780:I,Lod(I),Defl(I),Cod(I)
4360      ! IMAGE X,3D,4X,6D.D,4X,3D.7D,7X,3D.7D
4370   ! NEXT I
4380  ! WAIT 5
4390  K1=1
4400  K3=K
4410  GOSUB Slope              ! SLOPE = 1/COD COMPLIANCE
4420  Correl0(D2)=Correl       ! SAVES CURRENT CORRELATION COEFFICIENT IN AN ARRAY
4430  !
4440  Compl0(D2)=Compl         ! SAVES CURRENT COMPLINACE VALUE IN AN ARRAY
4450  !
4460  GOSUB Crack_length       ! USES COD COMPLIANCE
4470  !
4480  A0(D2)=Crckl             ! SAVE THE LAST a0 MEASUREMENT OBTAINED IN AN ARRAY
4490  !
4500  !  FIND 95% CONFIDENCE INTERVAL FOR a0
4510       Stiff=Stiff+T9*U4
4520       GOSUB Crack_length
4530       Amax0(D2)=Crckl
4540       Stiff=Stiff-2*T9*U4
4550       GOSUB Crack_length
4560       Amin0(D2)=Crckl
4570  !
4580  !
4590  PRINT CHR$(12)           ! CLEARS CRT
4600  PRINT "THE FOLLOWING INFORMATION HAS BEEN OBTAINED:"
4610  PRINT ""
4620  PRINT "INITIAL CRACK LENGTH (a0) =";A0(D2);"mm                 FROM MEASUREME
NT #";D2
4630  PRINT ""
4640  PRINT "WITH 95% CONDIFENCE INTERVAL ON a FROM";Amin0(D2);" TO";Amax0(D2);"
mm"
4650  PRINT ""
4660  PRINT "USING COD COMPLIANCE OF:";Compl0(D2);"mm/N"
4670  PRINT "WITH A CORRELATION OF:";Correl0(D2);"FROM";K;"DATA POINTS."
```

```
4680  PRINT ""
4690  PRINT "DO YOU WANT A HARD COPY?"
4700  INPUT H$
4710  IF H$="N" OR H$="NO" THEN 4830
4720  !
4730  PRINTER IS 706             ! TOGGLES PRINTER
4740  PRINT ""
4750  PRINT "THE FOLLOWING INFORMATION HAS BEEN OBTAINED:"
4760  PRINT "INITIAL CRACK LENGTH =";A0(D2);"mm FROM MEASUREMENT #";D2
4770  PRINT "WITH 95% CONFIDENCE INTERVAL FROM";Amin0(D2);" TO";Amax0(D2);"mm"
4780  PRINT "USING COD COMPLIANCE OF:";Compl0(D2);"mm/N"
4790  PRINT "WITH A CORRELATION OF:";Correl0(D2);"FROM";K;"DATA POINTS."
4800  PRINT ""
4810  PRINTER IS 1             ! TOGGLES PRINTER
4820  !
4830  D2=D2+1                    ! INCREMENT COUNTER
4840  PRINT ""
4850  PRINT "DO YOU WANT ANOTHER a0 MEASUREMENT?"
4860  INPUT G$
4870  IF G$="Y" OR G$="YES" THEN 4060
4880  !
4890  PRINT "INPUT THE NUMBER (#) OF THE a0 MEASUREMENT YOU    WISH TO USE AND S
TORE."
4900  PRINT "    NOTE: ONLY THIS SET OF DATA ARE"
4910  PRINT "           STORED ON DISK."
4920  INPUT D2
4930  !
4940  A1=A0(D2)     ! ASSIGNS A1 TO DESIRED A0(D2) VALUE
4950  ! NOTE: A1 IS USED IN Main_prog AS INITIAL CRACK LENGTH VALUE
4960  !
4970  PRINT ""
4980  PRINT "YOU HAVE SELECTED MEASUREMENT #";D2
4990  PRINT "        ARE YOU SURE?"
5000  INPUT P$
5010  ! NOTE: ONLY THIS a0 MEASUREMENT IS STORED ON DISK
5020  !
5030  IF P$="N" OR P$="NO" THEN 4890      ! ALLOWS CORRECTION
5040  K2=0                    ! K2 IS UNLOADING COUNTER THIS WILL ENSURE CORRECT DAT
A IS STORED
5050    GOSUB Stor_data   !  <-----------***  WRITES ON DISK
5060  !
5070  PRINT CHR$(12)
5080  !
5090  !
5100  RETURN           ! RETURNS TO k-KEY SELECTION
5110  !
5120  !*****************************************
5130  !
5140 Data_acq:   ! DATA ACQUISITION ROUTINE
5150    OUTPUT Dvm;"VR5 AF1 AL3"
5160    !
5170    OUTPUT Dvm;"AI1 VT1"       ! READS LOAD
5180    ENTER Dvm;Lod(I)
5190    Lod(I)=Lod(I)*Sl(1)
5200    !
5210    OUTPUT Dvm;"AI2 VT1"       ! READS COD
5220    ENTER Dvm;Cod(I)
5230    Cod(I)=(Cod(I))*Sl(2)
5240    ! NOTE: COD IS CALIBRATED ONLY FORM 0.475 TO 0.625 INCHES (MAX COD IS 0.1
5 INCHES)
```

```
5250    !
5260    OUTPUT Dvm:"AI3 VT1"      ! READS DEFLECTION
5270    ENTER Dvm:Defl(I)
5280    Defl(I)=Defl(I)*S1(3)
5290    !
5300    GOSUB Correct_defl       ! DETERMINE DEFL CORRECTION FACTOR
5310    !
5320    Defl(I)=Defl(I)-Totcor
5330    !
5340    !
5350    !    PLOT THE DATA POINT
5360    VIEWPORT 13,100*RATIO,10,90
5370    WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
5380    IF C2=2 THEN 5410
5390       PLOT Cod(I),Lod(I)
5400    GOTO 5420
5410       PLOT Defl(I),Lod(I)
5420    !
5430    ! TAKE DATA FOR ONE COMPLETE LOADING AND UNLOADING
5440    IF I=1 THEN 5520          ! SKIPS TEST ON THE FIRST DATA POINT
5450    !
5460    ! TEST DATA
5470    Lodiff=Lod(I)-Lod(I-1)
5480       IF Lodiff<-25.0 THEN Flag1=1    ! MUST BE    UNLOADING
5490       IF Lodiff>25.0 THEN Flag2=1     ! MUST BE   LOADING
5500    Lodiff=0.
5510    !
5520    I=I+1       ! INCREMENTS INDEX
5530    !
5540    K=K+1       ! INCREMENT COUNTER
5550    !
5560    RETURN      ! RETURNS TO Initial_a ROUTINE
5570    !
5580    !*******************************************
5590 Correct_defl:      ! THIS ROUTINE CALCULATES THE DEFLECTION CORRECTION FACT
OR
5600    !
5610    ! CORRECTION FACTOR IS REQUIRED TO ACCOUNT FOR SYSTEM COMPLIANCE
5620    ! A 4TH ORDER POLYNOMIAL FIT WAS PREVIOUSLY DETERMINED.
5630    !
5640    !     NOTE:  **********************
5650    ! THE 5 CORRECTION COEFFICIENTS CORR(I) WERE ASSIGNED IN Initial_a ROUTIN
E TO SPEED UP PROG.
5660    !        ***************************
5670    !
5680    Lodp=Lod(I)/Conlb    ! CONVERTS CURRENT LOAD TO Lbs FOR CALC
5690    Deflc(1)=Lodp
5700    FOR J=2 TO 4
5710       Deflc(J)=Deflc(J-1)*Deflc(1)
5720    NEXT J
5730    Totcor=Corr(1)       ! PREVIOUSLY ASSIGNED AS NOTED.
5740    FOR J=1 TO 4
5750       Totcor=Totcor+Corr(J+1)*Deflc(J)
5760    NEXT J
5770    !
5780    Totcor=Totcor*Conlen     ! CONVERTS TOTAL CORRECTION FACTOR FROM (in) TO (
mm)
5790    !
5800    !
5810    RETURN      ! RETURNS TO Data_acq OR Take_data ROUTINE
```

```
5820    !
5830    !**************************************
5840    !
5850 Crack_length: ! CALCULATES CRACK LENGTH USING HUDAK (DTNSRDC PROG) [PROF. J
. JOYCE'S EQUATION]
5860    !  NOTE: THIS ROUTINE USES COD COMPLIANCE  METHOD VICE DEFLECTION COMPLIA
NCE.
5870    FOR I=1 TO 6
5880       READ Coef(I)
5890    NEXT I
5900    Compl=1/Stiff
5910    C=2*W*Beff*E*Compl/Hs/1000
5920    C=1/(SQR(C)+1)
5930    G(1)=C
5940    FOR I=2 TO 5
5950       G(I)=G(I-1)*G(1)
5960    NEXT I
5970    F=Coef(1)
5980    FOR I=1 TO 5
5990       F=F+Coef(I+1)*G(I)
6000    NEXT I
6010    Crckl=F*W
6020    RESTORE
6030    DATA 0.998265,-3.81662,-1.80596,32.31038,-44.15665,-52.67876
6040    !
6050    RETURN          ! RETURNS TO Initial_a OR Main_prog
6060    !
6070    !****************************************
6080    !
6090 Conv_data:     ! INPUTS CONVERSION DATA FOR MEASURING DEVICES
6100    PRINT CHR$(12)            ! CLEARS CRT
6110    PRINT "INPUT: LOAD RANGE, STRAIN RANGE, STROKE RANGE"
6120    PRINT "     (ENTER IN PERCENT ie. 10,20,50,100)"
6130     INPUT Lr,Cr,Sr
6140    PRINT ""
6150    PRINT "LOAD RANGE = ";Lr
6160    PRINT "STRAIN (COD) RANGE = ";Cr
6170    PRINT "STROKE (DEFLECTION) RANGE = ";Sr
6180    Lmax=20000       ! MAX LOAD RANGE IN (lbs).
6190    Cmax=.200        ! MAX COD RANGE IN (in).
6200    Smax=5.0         ! MAX STROKE RANGE IN (in).
6210    V=10             ! MAX VOLTAGE IN (volts).
6220    !
6230    ! MAXIMUM OPERATING POINTS ARE:
6240    Olmax=Lmax*Lr/100
6250    Ocmax=Cmax*Cr/100
6260    Osmax=Smax*Sr/100
6270    !
6280    ! CONVERSION CONSTANTS ARE: (ENGLISH UNITS)
6290    Sle(1)=Olmax/V
6300    Sle(2)=Ocmax/V
6310    Sle(3)=Osmax/V
6320    ! CONVERTING TO METRIC:
6330    Conlen=25.4                ! 25.4mm = 1in
6340    Conlb=4.448221615         ! 4.448221615N = 1lb       (HP PROGRAMING BOOK)
6350    !
6360    ! Sle(1,2,3) IS USED TO DENOTE CONVERSION OF VOLTAGE TO ENGLISH UNITS.
6370    Sl(1)=Sle(1)*Conlb*(-1.0)    ! COMPRESSIVE LOAD IS NEGATIVE VOTLAGE
6380    Sl(2)=Sle(2)*Conlen
6390    Sl(3)=Sle(3)*Conlen*(-1.0)    ! COMPRESSIVE STROKE SUPPLIES A NEGATIVE VOL
TAGE
```

```
6400    !
6410    PRINT ""
6420    PRINT ""
6430    PRINT "YOUR ENTRIES HAVE PRODUCED THE FOLLOWING          CONVERSION DATA:
"
6440    PRINT ""
6450    PRINT "FOR LOAD: ";S1(1);"NEWTON/VOLT  (";S1e(1);"Lbs/V)"
6460    PRINT ""
6470    PRINT "FOR COD: ";S1(2);"mm/V  (";S1e(2);"in/V)"
6480    PRINT ""
6490    PRINT "FOR DEFLECTION: ";S1(3);"mm/V  (";S1e(3);"in/V)"
6500    PRINT ""
6510    PRINT "WOULD YOU LIKE A HARD COPY?"
6520    INPUT H$
6530    IF H$="N" OR H$="NO" THEN 6630
6540    !
6550    PRINTER IS 706          ! TOGGLES PRINTER
6560    PRINT ""
6570    PRINT "        CONVERSION DATA"
6580    PRINT "FOR LOAD:";S1(1);"N/V   (";S1e(1);"Lbs/V)"
6590    PRINT "FOR COD:";S1(2);"mm/V   (";S1e(2);"in/V)"
6600    PRINT "FOR DEFLECTION:";S1(3);"mm/V   (";S1e(3);"in/V)"
6610    PRINTER IS 1            ! TOGGLES PRINTER
6620    !
6630    PRINT CHR$(12)
6640    !
6650    RETURN          ! RETURNS TO k-KEY SELECTION
6660    !
6670    !*****************************************
6680    !
6690 Slope:   ! LINEAR LEAST SQUARES FIT
6700    PRINT CHR$(12)          ! CLEAR CRT
6710    ! INITIALIZE VARIABLES
6720    P2=0        ! USED AS A COUNTER
6730    Sumx=0      ! SUM OF X VALUES
6740    Sumx2=0     ! SUM OF X SQUARED VALUES
6750    Sumy=0      ! SUM OF Y VALUES
6760    Sumy2=0     ! SUM OF Y SQUARED VALUES
6770    Sumxy=0     ! SUM OF THE PRODUCT
6780    FOR I=K1 TO K3    ! K1=INDEX OF FIRST, K3=INDEX OF LAST DATA POINT USED.
6790       ! TYPE OF PLOT
6800       IF C2=1 THEN 6840          ! LOAD vs COD
6810       IF C2=2 THEN 6880          ! LOAD vs DEFL
6820       IF C2=3 THEN 6920          ! J vs DELTA_a
6830       !
6840       X=Cod(I)
6850       Y=Lod(I)
6860       GOTO 6990
6870       !
6880       X=Defl(I)
6890       Y=Lod(I)
6900       GOTO 6990
6910       !
6920       X=Delta_a(I)
6930       Y=J9(I)
6940       !
6950       ! CHECK IF DATA POINT IS WITHIN BOUNDS
6960       IF Delta_a(I)<J9(I)/(2*Fs)+.15 THEN 7050     ! CHECKS LOWER LIMIT
6970       IF Delta_a(I)>J9(I)/(2*Fs)+1.5 THEN 7050     ! CHECKS UPPER LIMIT
6980       !
6990       Sumx=Sumx+X
```

```
7000        Sumy=Sumy+Y
7010        Sumx2=Sumx2+X*X
7020        Sumy2=Sumy2+Y*Y
7030        Sumxy=Sumxy+X*Y
7040        GOTO 7060        ! GET NEXT DATA POINT
7050        P2=P2+1          ! INCREMENTS COUNTER EACH TIME A POINT IS ELIMINATED.
7060    NEXT I
7070    K3=K3-P2       ! USED TO CALCULATE NUMBER OF DATA POINTS WITHIN BOUNDS.
7080    K4=K3-K1+1          ! K4=TOTAL # DATA POINTS USED IN CALC
7090    Qa1=Sumx2-Sumx*Sumx/K4
7100    Qa2=Sumxy-Sumx*Sumy/K4
7110    Qa3=Sumy2-Sumy*Sumy/K4
7120    !
7130    M=Qa2/Qa1                  ! SLOPE
7140    !
7150    IF M<0 THEN 7430    ! IF SLOPE < 0, BAD DATA
7160    !  FROM DTNSRDC PROGRAM
7170    Q1=(K4*Sumx2-Sumx^2)/(K4*(K4-1))
7180    Q2=(K4*Sumy2-Sumy^2)/(K4*(K4-1))
7190    Q3=(K4-1)*(Q2-M*M*Q1)/(K4-2)
7200    Q4=SQR(Q3/(Q1*(K4-1)))
7210    !
7220    B=(Sumy-M*Sumx)/K4      ! INTERCEPT
7230    !
7240    Correl=M*SQR(Q1/Q2)
7250    !
7260    Qa4=SQR(ABS((Sumy2-B*Sumy-M*Sumxy)/(K4-2)))
7270    Sigmab=Qa4/SQR(ABS(Qa1))
7280    Sigmam=Sigmab*SQR(Sumx2/K4)
7290    Stiff=M                          ! STIFF = SLOPE
7300    Compl=1/M          ! COD COMPLIANCE = 1/SLOPE
7310    !
7320    ! STUDENT t TEST
7330    U4=Q4
7340    T9=1.96
7350    IF K4>120 THEN 7410           ! RETURNS
7360    T9=2.1
7370    IF K4<20 THEN 7410            ! RETURNS
7380    N9=K4-2
7390    T9=N9/(-.617109+N9*.510239)
7400    !
7410    RETURN
7420    !
7430    PRINT "POOR DATA-- SLOPE < 0"
7440    M=333333.3
7450    Correl=0
7460    !
7470    RETURN          ! RETURNS TO Initial_a, Main_prog or R_curve ROUTINE (WHICHE
VER CALLED IT)
7480    !
7490    !*****************************************
7500    !
7510 Data_file:      ! ESTABLISHES DATA FILE
7520    !  THE FILE YOU CREATE CAN BE READ BY THE   "J_DATA" PROGRAM
7530    !
7540    ! NOTE: ANY CHANGES MADE TO THIS ROUTINE MAY REQUIRE SIMILAR CHANGES TO "
J_DATA" PROGRAM DUE
7550    ! TO DISK FORMATTING CONSULT HP MANUAL FOR ASSISTANCE.
7560    !
7570    PRINT CHR$(12)     ! CLAERS CRT
```

```
7580   PRINT "THIS ROUTINE WILL CREATE A DATA FILE ON DISK FOR THE TEST."
7590   PRINT ""
7600   PRINT "INSERT AN INITIALIZED DATA DISK AND ENTER FILE      NAME (SAMPLE I
D IS SUGGESTED)."
7610   INPUT Name$
7620   PRINT ""
7630   PRINT "IS THIS A NEW FILE?"
7640   INPUT Q$
7650   IF Q$="N" OR Q$="NO" THEN 7680
7660   !
7670   CREATE BDAT Name$,6,40000
7680   ASSIGN @File TO Name$
7690   !
7700   PRINT ""
7710   PRINT "FOR RECORD PURPOSES THE FOLLOWING DATA IS ALSO      RECORDED:"
7720   PRINT ""
7730   PRINT "ENTER THE DATE (MM-DAY-YEAR):"
7740   INPUT Data$(1)
7750   PRINT ""
7760   PRINT "ENTER THE TIME (HH:MM):"
7770   INPUT Data$(2)
7780   PRINT ""
7790   PRINT "ENTER THE OPERATOR'S NAME:"
7800   PRINT "    (UP TO 10 CHARACTERS)"
7810   INPUT Data$(3)
7820   PRINT ""
7830   PRINT "ENTER SPECIMEN ID:"
7840   PRINT "    (UP TO 10 CHARACTERS)"
7850   INPUT Data$(4)
7860   ! WRITE ON DISK
7870   FOR I=1 TO 4
7880      OUTPUT @File;Data$(I)[1;10]
7890   NEXT I
7900   !
7910   BEEP
7920   PRINT ""
7930   PRINT "DATA FILE HAS BEEN CREATED."
7940   !
7950   !
7960   RETURN     ! RETURNS TO k-KEY SELECTION
7970   !
7980   !*********************************************
7990   !
8000 Stor_data:   ! WRITES DATA ON DISK
8010   !
8020   ! THE ITEMS STORED BY THIS ROUTINE CAN BE
8030   ! RECALLED USING THE "J_DATA" PROGRAM
8040   ! CARE MUST BE TAKEN IF ANY CHANGES ARE MADE TO THIS ROUTINE SUCH THAT SI
MILAR CHAGES ARE
8050   ! MADE TO THE "J_DATA" PROGRAM.
8060   !
8070   IF K2>0 THEN 8160        ! K2 IS UNLOADING COUNTER
8080      OUTPUT @File;A0(D2),Amin0(D2),Amax0(D2),Compl0(D2),Correl0(D2),K
8090   !
8100   PRINT ""
8110   PRINT ""
8120   PRINT "INITIAL CRACK LENGTH (a0) INFORMATION FROM        MEASUREMENT #";
D2
8130   PRINT "IS NOW IN DISK FILE ";Name$
8140   !
```

```
8150   IF K2=0 THEN 8220       ! SKIP IF THIS WAS  a0 MEASUREMENT
8160      OUTPUT @File:K2,A1(K2),Delta_a(K2),K,L,Correl,Compl,Amin,Amax,Area9(K2
),J9(K2)
8170      OUTPUT @File:Mdefl(K2),Codiff,K0,K1
8180   !
8190   PRINT ""
8200   PRINT "UNLOADING INFORMATION IS NOW IN DISK FILE ";Name$
8210   !
8220   BEEP
8230   ! WAIT 3      ! ALLOWS A PAUSE SO MESSAGE IS PRESENTED ON THE CRT
8240   !
8250   !
8260   RETURN      ! RETURNS TO Initial_a OR Main_prog
8270   !
8280   !****************************************
8290   !
8300 Take_data:  ! THIS ROUTINE IS USED TO TAKE DATA DURING THE ACTUAL TEST.
8310   !
8320   I=K                           ! INDEX
8330   OUTPUT Dvm:"AI1 VT1"          ! READS LOAD
8340   ENTER Dvm:Lod(I)
8350   Lod(I)=Lod(I)*S1(1)
8360   !
8370   OUTPUT Dvm:"AI2 VT1"      ! READS COD
8380   ENTER Dvm:Cod(I)
8390   Cod(I)=Cod(I)*S1(2)
8400   !
8410   OUTPUT Dvm:"AI3 VT1"      ! READS DEFLECTION
8420   ENTER Dvm:Defl(I)
8430   Defl(I)=Defl(I)*S1(3)
8440   !
8450   GOSUB Correct_defl        ! DETERMINE CORRECTION FACTOR FOR SYSTEM COMPLIA
NCE
8460   !
8470   Defl(I)=Defl(I)-Totcor
8480   !
8490   !   PLOT THE DATA POINT
8500   VIEWPORT 13,100*RATIO,10,90
8510   WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
8520   IF C2=2 THEN 8550
8530      PLOT Cod(I),Lod(I)
8540   GOTO 8560
8550      PLOT Defl(I),Lod(I)
8560   !
8570   !
8580   RETURN      ! RETURNS TO Main_prog
8590   !
8600   !****************************************
8610   !
8620 J_calc:  ! CALCULATES J WITH CRACK GROWTH CORRECTION ERNST MODEL (USED BY D
TNSRDC)
8630   !
8640   E5=2
8650   !  CALCULATE J FOR FIRST (1st) UNLOADING
8660   IF K2>1 THEN 8690
8670   J6=J7+E5/(W-A1(K2))*Area9(K2)/Bmin
8680   GOTO 8730
8690   J6=J7+E5/(W-A1(K2))*(Area9(K2)-Area9(K2-1))/Bmin
8700   ! IF DELTA_a < 0.254mm DO NOT USE CRACK GROWTH CORRECTION
8710   IF Delta_a(K2)<.254 THEN 8730
```

```
8720   J6=J6*(1-1/(W-A1(K2))*(A1(K2)-A1(K2-1)))   ! CORRECTS FOR CRACK GROWTH (A
STM E813-81)
8730   J7=J6
8740   !
8750   J9(K2)=J6         ! STORES CURRENT J VALUE IN  J9 ARRAY.
8760   !
8770   RETURN       ! RETURNS TO Main_prog
8780   !
8790   !*******************************************
8800   !
8810 Main_prog:  ! THIS IS THE MAIN PROGRAM FOR   THE J-INTEGRAL TEST.
8820   !
8830   PRINT CHR$(12)       ! CLEARS CRT
8840   PRINT ""
8850   PRINT "ENSURE YOU HAVE COMPLETED THE FOLLOWING ITEMS         BEFORE PROCE
EDING:"
8860   PRINT "    1. ENTERED SPECIMEN DATA."
8870   PRINT "    2. ENTERED CONVERSION DATA."
8880   PRINT "    3. SET UP INTEACTIVE PLOTTER."
8890   PRINT "    4. OBTAINED INITIAL CRACK LENGTH."
8900   PRINT ""
8910   PRINT " ARE YOU READY?"
8920   INPUT H$
8930   IF H$="NO" OR H$="N" THEN 10530  ! RETURNS TO WAIT FOR k-KEY SELECTION
8940   PRINT ""
8950   PRINT ""
8960   PRINT "WHAT IS YOUR EXPECTED MAXIMUM LOAD IN NEWTONS?"
8970   INPUT Pmax
8980   Lod5=.1*Pmax      ! USED TO SIGNAL TURN AROUND FROM UNLOADING
8990   !
9000   PRINT "THE TEST SHOULD START WITH NEAR ZERO (0) LOAD WITH THE MTS IN 'STR
OKE' CONTROL."
9010   PRINT ""
9020   PRINT "ENSURE THIS IS DONE."
9030   PRINT ""
9040   PRINT "WHEN YOU ARE READY PRESS 'ENTER' OR 'CONTINUE' KEY AND START THE M
TS MACHINE."
9050   INPUT H$
9060   PRINT CHR$(12)       ! CLEARS CRT
9070   !
9080   !
9090   !  INITIALIZE VARIABLES
9100   Area=0     ! AREA UNDER LOAD vs DEFLECTION CURVE   DTNSRDC (I8)
9110   Area9(1)=0 ! AREA BENEATH SPECIFIC LOD vs DEFL (DTNSRDC I9(K2))
9120   K=K        ! CURRENT INDEX (AFTER OBTAINING INITIAL CRACK LENGTH)
9130   I=K        ! INDEX OF FIRST TEST DATA POINT
9140   K0=K       ! WHERE TEST DATA STARTS
9150   K1=0       ! LOWER INDEX FOR SLOPE CALC
9160   K2=0       ! A COUNTER       "    (K2)  NUMBER OF UNLOADINGS
9170   K3=0       ! UPPER INDEX FOR SLOPE CALC
9180   L=1        ! A COUNTER    DTNSRDC (L)       "   "  DATA POINTS TAKEN DURING
UNLOADING
9190   Lod1=0     ! TEMP LOAD        "     (P1)  USED IN AREA CALC
9200   Lod2=0     ! TEMP LOAD        "     (P2)    "   "   "   "
9210   Lod5=.1*Pmax  !               "     (P5)  USED FOR TURN AROUND SIGNAL
9220   Lod9=0     ! MAX LOAD         "     (P9)
9230   Cod1=0     ! TEMP COD         "     (D1)
9240   Cod2=0     ! TEMP COD         "     (D2)
9250   Cod4=0     ! TEMP COD         "     (C4)
```

```
9260    Cod9=0     ! MAX COD          "    (D9)
9270    Codiff=0   ! COD DIFFERENCE "    (D3)
9280    Defl1=0    ! TEMP DEFL        "    (D4)  USED IN AREA CALC
9290    Defl2=0    ! TEMP DEFL        "    (D5)    "   "   "    "
9300    J6=0       ! JI FROM CURRENT UNLOAD
9310    J7=0       ! JI FROM PREVIOUS UNLOAD DTNSDRC (J7)
9320    I1=0       ! FLAG (0=LOADING, 1=UNLOADING)
9330    F1=0       ! FLAG (F1=999 ENDS TEST)
9340    !
9350    !
9360    PRINT ""
9370    !
9380    IF F1=999 THEN GOSUB End_test
9390    !
9400    GOSUB Take_data
9410    Defl6=Defl(I)
9420    Lod7=Lod(I)
9430    Lod2=Lod(I)
9440    Defl2=Defl(I)
9450    Cod2=Cod(I)
9460    !
9470    ! TEST CONDITIONS OF DATA POINT JUST TAKEN
9480    IF (K-K0)<20 THEN 10430   ! CALC AREA & TAKE MORE DATA
9490    Codiff=Cod2-Cod1
9500    IF Codiff<-3.0E-4 THEN 9540   ! IF CODIFF IS (-) CHECK IF LOADING OR UNLO
ADING
9510    IF I1=0 THEN 10430   ! IF LOADING CALC AREA & TAKE MORE DATA
9520    IF Cod2>Cod9 THEN 9600   ! IF TRUE CHECK IF GOOD UNLOADING
9530    GOTO 10340             ! DISREGARD UPPER 2% OF UNLOADING CURVE
9540    IF I1<>0 THEN 10340    ! IF UNLOADING CHECK  IF ON UPPER 2% OF CURVE
9550    Lod9=Lod2              ! IF LOADING MAKE CURRENT LOAD = MAXIMUM LOAD
9560    Cod9=Cod2              ! MAKE CURRENT COD = MAX COD
9570    Defl9=Defl2            ! MAKE CURRENT DEFL = MAX DEFL
9580    I1=1               ! MUST BE UNLOADING .
9590    GOTO 10340         ! TEST IF UPPER 2% OF UNLOADING
9600    IF L<5 THEN 10290 ! BAD UNLOADING, SET I1=1
9610    K1=K-L              ! SETS LOWER INDEX FOR SLOPE CALCULATION.
9620    K3=K1+L             ! SETS UPPER INDEX FOR SLOPE CALCULATION.
9630    PENUP
9640    !
9650    K2=K2+1             ! INCREMENT UNLOADING COUNTER
9660    !
9670    GOSUB Slope         ! IF GOOD UNLOADING
9680    Stiff2=Stiff
9690    GOSUB Crack_length     ! CALC CRACK LENGTH
9700    Al(K2)=Crckl           ! CURRENT CRACK LENGTH
9710    Delta_a(K2)=Al(K2)-A1          ! DETERMINE CRACK GROWTH
9720    !
9730    ! NOTE: A1 = INITIAL CRACK LENGTH; ASSIGNED IN Initial_a ROUTINE.
9740    !
9750    Crckl4=Crckl
9760    PRINT "        ----  UNLOADING #";K2;" ---"
9770    ! PRINT ""
9780    PRINT "CRACK LENGTH =";Al(K2);"mm"
9790    PRINT "DELTA_a =";Delta_a(K2);"mm"
9800    PRINT "TOTAL # DATA POINTS = ";K
9810    PRINT "# DATA POINTS THIS UNLOADING =";L
9820    PRINT "CORRELATION =";Correl
9830    PRINT "COD COMPLIANCE =";Compl;"mm/N"
```

```
9840    !
9850    Area9(K2)=Area
9860    !
9870    ! CALCULATE 95% CONFIDENCE INTERVAL
9880    Stiff=Stiff+T9*U4
9890    GOSUB Crack_length
9900    Amax=Crckl
9910    Stiff=Stiff-2*T9*U4
9920    GOSUB Crack_length
9930    Stiff=Stiff2
9940    Amin=Crckl
9950    PRINT ""
9960    PRINT "95% CONFIDENCE INTERVAL ON CRACK LENGTH FROM ";Amin;"TO";Amax
9970    !
9980    GOSUB J_calc  ! CALC J (USES J-ERNST MODEL)
9990    !
10000   Mdefl(K2)=Defl(K)      ! MAX DEFLECTION
10010   !
10020   ! PRINT ""
10030   PRINT "AREA =";Area9(K2);"N*mm"
10040   PRINT "J =";J9(K2):"KJ/m^2"
10050   PRINT "LOAD LINE DEFLECTION =";Mdefl(K2);"mm"
10060   PRINT "CHANGE IN COD =";Codiff;"mm"
10070   PRINT "K0=";K0;"  K1=";K1
10080   !
10090   !
10100   GOSUB Prt_results              ! PRINTS RESULTS ON PRINTER
10110   !
10120   ! DATA POINTS CAN BE PRESENTED FOR REVIEW BY SIMPLY REMOVING THE REMARK C
HARACTER (!).
10130   PRINT ""
10140   ! PRINT " PT #    LOAD(N)       DEFLECTION(mm)   COD(mm)"
10150   ! FOR I=(K1-1) TO K
10160     ! PRINT USING 9170:I.Lod(I),Defl(I).Cod(I)
10170     ! IMAGE 4D,4X,5D.D,6X,DD.6D.7X,DD.6D
10180   ! NEXT I
10190   ! WAIT 5          ! PAUSE TO ALLOW VIEWING
10200   !
10210   !
10220   GOSUB Stor_data        ! STORES INFORMATION ON DISK
10230   !
10240   !
10250   IF Crckl4-A1>0 THEN 10290
10260   PRINT ""
10270   PRINT "    NO  CRACK  EXTENSION  THIS  POINT."
10280   PRINT ""
10290   I1=0
10300   L=1
10310   ! IF L=1 THEN K1=K   ! SETS LOWER INDEX FOR  SLOPE CALCULATION AT CURRENT
 K
10320   GOTO 10360
10330   IF Cod2<Cod1 THEN 10440   !  GET MORE DATA
10340   IF Lod2>.98*Lod9 THEN 10440     ! DISREGARD UPPER 2% OF UNLOADING & GET MO
RE DATA
10350   L=L+1          ! INCREMENT DATA POINT COUNTER
10360   IF Lod2>Lod9-Lod5 THEN 10440       ! IF TRUE GET MORE DATA
10370   BEEP          ! SENDS OUT BEEP
10380   BEEP          ! AS TURN AROUND
10390   BEEP          ! SIGNAL TO BEGIN RELOADING
10400   GOTO 10440   ! RESUME TAKING AND TEST DATA
10410   !
10420   !   CALCULATE AREA UNDER LOAD vs DEFLECTION CURVE
```

```
10430  Area=Area+(Defl2-Defl1)*(Lod2+Lod1)/2
10440  Lod1=Lod2
10450  K=K+1         ! INCREMENT TOTAL # DATA POINTS COUNTER
10460  Cod1=Cod2
10470  Defl1=Defl2
10480  !
10490  GOTO 9380      ! LOOP BACK CHECK IF TEST IS
10500  !                OVER, IF NOT TAKE MORE DATA.
10510  !
10520  !
10530  RETURN       ! NEVER REACH THIS BUT ROUTINE WOULD NOT BE VALID WITHOUT IT
10540  !
10550  !*****************************************
10560 Prt_results:       ! PRINTS TEST INFORMATION WHILE PROGRAM IS RUNNING
10570  PRINTER IS 706    ! TOGGLES PRINTER
10580  PRINT ""
10590  PRINT "       ----  UNLOADING #";K2;" ----"
10600  PRINT ""
10610  PRINT "CRACK LENGTH =";Al(K2);"mm    DELTA _a =";Delta_a(K2);"mm"
10620  PRINT "95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM";Amin;" TO";Amax
10630  PRINT ""
10640  PRINT "TOTAL # DATA POINTS =";K;"    # DATA POINTS THIS UNLOADING =";L
10650  PRINT "CORRELATION =";Correl
10660  PRINT "COD COMPLIANCE =";Compl;"mm/N"
10670  PRINT ""
10680  PRINT "AREA =";Area9(K2);"N*mm"
10690  PRINT "J =";J9(K2);"KJ/m^2"
10700  PRINT "MAX LOAD LINE DEFLECTION =";Mdefl(K2);"mm"
10710  PRINT "CHANGE IN COD =";Codiff;"mm"
10720  !
10730  PRINT ""
10740  PRINTER IS 1     ! TOGGLES PRINTER TO CRT
10750  !
10760  RETURN           ! RETURNS TO Main_prog
10770  !
10780  !*****************************************
10790  !
10800 Stor_arrays:  ! STORES ARRAYS (Lod,Defl,Cod) ON DISK
10810  !
10820  ! THE ARRRAYS CAN BE RECALLED LATER USING
10830  ! THE "J_DATA" PROGRAM.
10840  !
10850     OUTPUT @File;Lod(*),END
10860     OUTPUT @File;Defl(*),END
10870     OUTPUT @File;Cod(*),END
10880  !
10890  BEEP
10900  !
10910  !
10920  RETURN       ! RETURNS TO End_test
10930  !
10940  !*****************************************
10950  !
10960 End_test:     ! ENDS TEST
10970  !
10980  PRINT CHR$(12)
10990  !
11000  !
11010  GOSUB Stor_arrays
11020  !
```

```
11030  PRINT "DATA HAS BEEN STORED ON DISK IN FILE ";Name$
11040  !
11050  GOSUB R_curve
11060  !
11070  PRINT ""
11080  PRINT "  TEST IS OVER!!"
11090  PRINT ""
11100  PRINT ""
11110  PRINT ""
11120  PRINT ""
11130  PRINT ""
11140  PRINT "       TEST IS OVER!"
11150  PRINT ""
11160  PRINT ""
11170  PRINT ""
11180  PRINT ""
11190  PRINT ""
11200  PRINT "            TEST IS OVER!"
11210  !
11220  !
11230  GOTO 12590       ! GO TO END STATEMENT
11240  !
11250  RETURN   ! NEVER REACH THIS POINT BUT ROUTINE WOULD NOT BE VALID WITHOUT
IT
11260  !
11270  !******************************************
11280  !
11290 R_curve:  ! J vs DELTA_a DATA  IS PRESENTED FOR PLOTTING
11300  !
11310  PRINT ""
11320  !
11330  ! ALL (*) STATEMENTS WILL ALLOW DIRECT INPUT OF Delta_a(I) vs J9(I) DATA
11340  ! YOU MUST REMOVE [!(*)] FROM BEGINNING OF EACH LINE TO ACTIVATE
11350  !(*) PRINT "INPUT THE # OF UNLOADINGS"
11360  !(*) INPUT K2
11370  !(*) PRINT "ENTER DELTA_A(I),J9(I)"
11380  PRINT "UNLOADING #   DELTA_a(mm)     J(kJ/m^2)"
11390  FOR I=1 TO K2
11400     !(*) INPUT Delta_a(I),J9(I)
11410     PRINT USING 11420;I,Delta_a(I),J9(I)
11420     IMAGE 6X,3D,4X,DD.6D,5X,6D.D
11430  NEXT I
11440  PRINT ""
11450  PRINT "DO YOU WANT A HARD COPY?"
11460  INPUT H$
11470  IF H$="N" OR H$="NO" THEN 11680
11480  !
11490  PRINTER IS 706        ! TOGGLES TO THERMAL PRINTER
11500  PRINT "UNLOADING #    DELTA_a(mm)    J(kJ/m^2)"
11510  FOR I=1 TO K2
11520     PRINT USING 11420;I,Delta_a(I),J9(I)
11530  NEXT I
11540  PRINTER IS 1     ! RETURNS TO CRT AS PRINTER
11550  !
11560  !(*) PRINT "ARE ALL OKAY?"
11570  !(*) INPUT G$
11580  !(*) IF G$="Y" THEN 11582
11590  !(*) PRINT "INPUT I (INDEX) OF BAD #"
11600  !(*) INPUT L1
11610  !(*) PRINT "INPUT VALUES OF DELTA_A(I) AND J9(I)"
```

```
11620  !(*) INPUT Delta_a(L1),J9(L1)
11630  !(*) PRINT "ARE YOU OK"
11640  !(*) INPUT Eee$
11650  !(*) IF Eee$="N" THEN GOTO 11574
11660  ! END OF (*) CHANGES REQUIRED FOR DIRECT INPUT OF DELTA_A(I) vs J9(I) DAT
A
11670  !
11680  PRINT ""
11690  PRINT "DO YOU WANT A PLOT OF J vs DELTA_a?"
11700  INPUT R$
11710  IF R$="N" OR R$="NO" THEN 12550
11720  PRINT ""
11730  PRINT "WHEN THE PLOTTER IS READY (NEW GRAPH PAPER INSTALLED) PRESS 'ENTER
' OR 'CONTINUE' KEY"
11740  INPUT C$
11750  !
11760  GOSUB Setup_plotter
11770  !
11780  ! PLOT THE DATA THE DATA POINTS
11790  VIEWPORT 13,100*RATIO,10,90
11800  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
11810  FOR I=1 TO K2
11820     X=Delta_a(I)
11830     Y=J9(I)
11840     MOVE X-X3*.005,Y+Y3*.005       ! DRAWS A
11850     DRAW X+X3*.005,Y-Y3*.005       ! SMALL X
11860     MOVE X+X3*.005,Y+Y3*.005       ! FOR DATA
11870     DRAW X-X3*.005,Y-Y3*.005       ! POINT
11880  NEXT I
11890  !
11900  ! PLOT THE BLUNTING LINE
11910  VIEWPORT 13,100*RATIO,10,90
11920  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
11930     Bly=Y2(C2)-Y3/8      ! TAKES LINE TO 7/8 OF Ymax
11940     Blx=Bly/(2*Fs)*1000      ! DELTA_a = J/2*Fs
11950       MOVE 0,0
11960       DRAW Blx,Bly
11970       !
11980       Blminx=Blx+.15     ! DRAWS LOWER BOUNDS
11990       MOVE .15,0
12000       LINE TYPE 4
12010       DRAW Blminx,Bly
12020       !
12030       Blmaxx=Blx+1.5     ! DRAWS UPPER BOUNDS
12040       MOVE 1.5,0
12050       LINE TYPE 4
12060       DRAW Blmaxx,Bly
12070       PENUP
12080       !
12090  K1=1                     ! LOWER INDEX FOR LEAST SQUARES FIT
12100  K3=K2                    ! UPPER INDEX
12110  GOSUB Slope
12120  !
12130  ! PLOT THE LINE OBTAINED
12140  VIEWPORT 13,100*RATIO,10,90
12150  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
12160     Xplt=X2(C2)-X3/8     ! TAKES LINE TO 7/8 OF Xmax
12170     Yplt=Xplt*M+B
12180     MOVE 0,B
12190     LINE TYPE 6
```

```
12200     DRAW Xplt,Yplt
12210     PENUP
12220  PRINT ""
12230  PRINT "ONLY DATA WITHIN BOUNDS IS USED"
12240  PRINT "FOR LEAST SQUARES FIT."
12250  PRINT ""
12260  PRINT "SLOPE=";M;" INTERCEPT=";B
12270  PRINT "CORREL=";Correl
12280  PRINT "NUMBER OF DATA POINTS USED:";K4
12290  !
12300  PRINTER IS 706         ! TOGGLES PRINTER
12310  PRINT ""
12320  PRINT ""
12330  PRINT "DATA FROM J vs DELTA_a PLOT"
12340  PRINT ""
12350  PRINT "SLOPE =";M;"   Y-INTERCEPT =";B
12360  PRINT "CORRELATION =";Correl;"  FROM";K4;" DATA POINTS."
12370  PRINTER IS 1           ! TOGGLES PRINTER
12380  !
12390  ! FIND THE INTERSECTION, HENCE J(1c).
12400  ! SOLVE BOTH EQUATIONS SIMULTANEOUSLY
12410  ! J = M*(DELTA_a)+B = (DELTA_a)*(2*Fs)  HENCE:
12420  J1c=(B/M)/(1/M-(1000/(2*Fs)))
12430  PRINT ""
12440  PRINT "     J1c =";J1c
12450  PRINTER IS 706          ! TOGGLES PRINTER
12460  PRINT ""
12470  PRINT "      J1c =";J1c
12480  PRINT ""
12490  PRINT ""
12500  PRINT " TEST IS OVER!"
12510  PRINTER IS 1            ! TOGGLES PRINTER
12520  !
12530  ! GOTO 12100      ! GO TO END STATEMENT
12540  !
12550  RETURN        ! RETURNS TO End_test ROUTINE
12560  !
12570  !*****************************************
12580  !
12590 END                ! END OF TEST AND PROGRAM
12600  !
12610  !*****************************************
12620  !
12630 SUB Stop_test           ! STOPS TEST
12640  !          k9-KEY ACTS AS PROGRAM INTERRUPT
12650  ! k9-KEY IS NOT LABELED, BUT IS ASSIGNED A HIGHER PRIORITY TI INTERRUPT P
ROGRAM
12660  !
12670  COM /J_intgl/ F1
12680  F1=999              ! SETS STOP FLAG
12690  !
12700 SUBEND
12710  !*****************************************
```

APPENDIX F

J_DATA LISTING

```
10     !              J_DATA PROGRAM
20     ! THIS PROGRAM WILL ALLOW YOU TO READ A DATA
30     ! FILE CREATED BY "J_INTGL".  YOU MUST KNOW
40     ! HOW MANY UNLOADINGS WERE RECORDED DURING
50     ! THE TEST TO USE THIS PROGRAM.
60     !
70     ! PROGRAM WAS WRITTEN BY:
80     !    LCDR W.K. TRITCHLER
90     ! VERSION 1.0     DATE 11/83
100    !
110    !
120    !
130    DIM Data$(1:4)[10]
140    DIM Lod(8000).Defl(8000),Cod(8000)
150    DIM Al(100).Area9(100).Delta_a(100)
160    DIM Mdefl(100),J9(100)
170    !
180    PRINT CHR$(12)     ! CLEARS CRT
190    !
200    DUMP DEVICE IS 706
210    PRINT "WHAT DATA FILE DO YOU WISH TO READ?"
220    INPUT Name$
230    ASSIGN @File TO Name$
240    FOR I=1 TO 4
250      ENTER @File:Data$(I)[1:10]
260    NEXT I
270    PRINT ""
280    PRINT "J-INTEGRAL TEST OF ";Data$(4);"BY: ";Data$(3)
290    PRINT ""
300    PRINT "DATE: ";Data$(1);"      TIME: ";Data$(2)
310       ENTER @File;Crckl,Amin,Amax,Compl,Correl,K
320    PRINT ""
330    PRINT ""
340    PRINT ""
350    PRINT "a0=";Crckl,"WITH 95% CONDIFENCE INTERVAL  FROM";Amin;"   TO";Amax
360    PRINT ""
370    PRINT "FROM COMPLIANCE = ";Compl
380    PRINT ""
390    PRINT "CORRELATION=";Correl;"FROM";K;"DATA POINTS"
400    PRINT ""
410    PRINT "DO YOU WANT A HARD COPY OF THIS INFORMATION?"
420    INPUT G$
430    IF G$="N" OR G$="NO" THEN 450
440    DUMP ALPHA
450    PRINT ""
460    PRINT "INPUT THE NUMBER OF UNLOADINGS THAT WERE RECORDED DURING THE TEST."
470    INPUT C1             ! WILL BE USED AS COUNTER
480    FOR I=1 TO C1
490       ENTER @File;K2,Al(K2),Delta_a(K2),K,L,Correl,Compl,Amin,Amax,Area9(K2),
J9(K2)
500       ENTER @File:Mdefl(K2),Codiff,K0.K1
510       GOSUB Prt_results      ! DISPLAYS INFO
520       PRINT ""
530       PRINT "DO YOU WANT A HARD COPY?"
540       INPUT Q$
550       IF Q$="N" OR Q$="NO" THEN 580
560       PRINTER IS 706
570       GOSUB Prt_results     ! WILL NOW PRINT INFO
580    NEXT I
590    PRINT "DO YOU WANT A LISTING OF THE DATA POINTS?"
```

```
600   INPUT E$
610   IF E$="N" OR E$="NO" THEN 830
620   PRINT ""
630   PRINT "PT #    LOAD (N)     DEFLECTION (mm)    COD (mm)"
640   ENTER @File:Lod(*).Defl(*).Cod(*)
650   FOR I=1 TO K
660      PRINT USING 670:I.Lod(I).Defl(I).Cod(I)
670      IMAGE X,4D.3X,5D.D,8X,D.6D.8X,D.6D
680   NEXT I
690   PRINT ""
700   PRINT "DO YOU WANT A HARD COPY?"
710   INPUT H$
720   IF H$="N" OR H$="NO" THEN 830
730   PRINTER IS 706
740   PRINT "DATA FROM a0 FOR:";Data$(4);"BY: ";Data$(3)
750   PRINT ""
760   PRINT "TESTED ON: ";Data$(1);"TIME: ";Data$(2)
770   PRINT ""
780   PRINT "PT #    LOAD (N)     DEFLECTION (mm)    COD (mm)"
790   FOR I=1 TO K
800      PRINT USING 670:I.Lod(I).Defl(I).Cod(I)
810   NEXT I
820   PRINTER IS 1
830   PRINT CHR$(12)          ! CLEARS CRT
840   PRINT "DO YOU WISH TO PLOT ANY DATA?"
850   INPUT P$
860   IF E$="Y" OR E$="YES" THEN 880  ! OTHERWISE MUST NOW READ DATA POINTS OFF
DISKETTE
870   ENTER @File:Lod(*).Defl(*).Cod(*)
880   IF P$="Y" OR P$="YES" THEN GOSUB Setup_plotter
890   PRINT "DO YOU WANT ANOTHER PLOT?"
900   INPUT A$
910   IF A$="Y" OR A$="YES" THEN GOSUB Setup_plotter
920   PRINT "DO YOU WANT ANOTHER PLOT?"
930   INPUT F$
940   IF F$="Y" OR F$="YES" THEN GOSUB Setup_plotter
950   PRINT "    PROGRAM IS OVER!!!"
960   PRINT ""
970   PRINT ""
980   PRINT ""
990   PRINT ""
1000  PRINT ""
1010  PRINT "              PROGRAM IS OVER!"
1020  PRINT ""
1030  PRINT ""
1040  PRINT ""
1050  PRINT ""
1060  PRINT ""
1070  PRINT "                      PROGRAM IS OVER!"
1080  !
1090  GOTO 1290
1100  !
1110  !*******************************************
1120  !
1130 Prt_results:   ! DISPLAYS OR PRINTS UNLOADING INFORMATION
1140  PRINT ""
1150  PRINT "FROM UNLOADING #":K2:"RECORDED";L:"DATA POINTS"
1160  PRINT "COD COMPLIANCE =";Compl;"mm/N   CORRELATION =";Correl
1170  PRINT "CRACK LENGTH =";Al(K2);"mm   DELTA_A =";Delta_a(K2);"mm"
1180  PRINT "95% CONFIDENCE INTERVAL FROM";Amin;"mm TO";Amax:"mm"
```

```
1190  PRINT "AREA =";Area9(K2):"N*mm    J =";J9(K2);"KPa*m"
1200  PRINT "DATA POINT INDEXES FROM";K1;"TO";K:" WERE USED."
1210  PRINT ""
1220  PRINTER IS 1
1230  !
1240  RETURN
1250  !
1260  !*******************************************
1270  !
1280 Setup_plotter:      ! SET UP PLOTTER
1290  ! YOU CAN CHOOSE BETWEEN THREE DIFFERENT PLOTS
1300  PRINT CHR$(12)      ! CLEARS CRT
1310  DIM T$[80],X$[80],Y$[80]
1320  GCLEAR
1330  GINIT
1340  GRAPHICS ON
1350  PLOTTER IS 3,"INTERNAL"    ! PLOTS ON CRT
1360  PRINT "TYPE OF PLOT:"
1370  PRINT "     1.  LOAD vs COD"
1380  PRINT "     2.  LOAD vs DEFLECTION"
1390  PRINT "     3.  J vs CRACK EXTENSION"
1400  PRINT "ENTER THE # OF THE  PLOT YOU DESIRE"
1410  INPUT C2
1420  PRINT ""
1430  PRINT ""
1440  IF C2=1 THEN 1470
1450  IF C2=2 THEN 1520
1460  IF C2=3 THEN 1570
1470  T$="PLOT of LOAD vs COD for "&Data$(4)
1480  PRINT T$
1490  X$="COD (mm)"
1500  Y$="LOAD (N)"
1510  GOTO 1610
1520  T$="PLOT of LOAD vs DEFLECTION for "&Data$(4)
1530  PRINT T$
1540  X$="DEFLECTION (mm)"
1550  Y$="LOAD (N)"
1560  GOTO 1610
1570  T$="PLOT OF J vs CRACK EXTENSION for "&Data$(4)
1580  PRINT T$
1590  X$="DELTA_a (mm)"
1600  Y$="J  (kJ/m^2)"
1610  PRINT ""
1620  PRINT "USING METRIC UNITS (mm,N,kJ/m^2,etc.):"
1630  PRINT "ENTER THE  Xmin,Xmax,Ymin,Ymax"
1640  INPUT X1(C2),X2(C2),Y1(C2),Y2(C2)
1650  X3=X2(C2)-X1(C2)
1660  Y3=Y2(C2)-Y1(C2)
1670  VIEWPORT 13,100*RATIO,10,90
1680  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
1690  PRINT ""
1700  PRINT "INPUT DELTA_X AND DELTA_Y LABEL INTERVAL"
1710  PRINT "FOR THE TWO AXES:"
1720  INPUT X4,Y4
1730  PRINT ""
1740  PRINT "DO YOU WISH TO HAVE A GRID OVERLAY?"
1750  INPUT G$
1760  IF G$="N" OR G$="NO" THEN 1800
1770  PRINT ""
1780  PRINT "INPUT GRID LINES PER DELTA LABEL:"
```

```
1790  INPUT B0
1800  PRINT "PRESS 'ENTER' OR 'CONTINUE' KEY TO PLOT"
1810  INPUT H$          ! DUMMY VARIABLE
1820  PRINT CHR$(12)    ! CLEARS CRT
1830  IF G$="N" OR G$="NO" THEN 1970
1840  FOR I=X4/B0+X1(C2) TO X2(C2) STEP X4/B0
1850     MOVE I,Y1(C2)
1860     DRAW I,Y2(C2)
1870  NEXT I
1880  FOR I=Y4/B0+Y1(C2) TO Y2(C2) STEP Y4/B0
1890     MOVE X1(C2),I
1900     DRAW X2(C2),I
1910  NEXT I
1920  GOTO 1970
1930  IF G$="Y" OR G$="YES" THEN 1970
1940  MOVE X2(C2),Y1(C2)
1950  DRAW X2(C2),Y2(C2)
1960  DRAW X1(C2),Y2(C2)
1970  CLIP ON
1980  AXES X4,Y4,X1(C2),Y1(C2)
1990  CLIP OFF
2000  VIEWPORT 13,100*RATIO,5,90
2010  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
2020  LORG 4
2030  CSIZE 3,.6
2040  FOR X=X1(C2) TO X2(C2) STEP X4
2050     CLIP OFF
2060     MOVE X,Y1(C2)
2070     LABEL USING "K";X        ! PLOTS X-DIGITS
2080  NEXT X
2090  VIEWPORT 4,100*RATIO,10,90
2100  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
2110  LORG 2
2120  FOR Y=Y1(C2) TO Y2(C2) STEP Y4
2130     CLIP OFF
2140     MOVE X1(C2),Y
2150     LABEL USING "K";Y
2160  NEXT Y
2170  VIEWPORT 0,100*RATIO,0,100
2180  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
2190  CSIZE 5
2200  LORG 6          ! PLOTS TITLE
2210      MOVE X2(C2)/2,Y2(C2)
2220      LABEL T$
2230  DEG
2240  LDIR 90
2250  CSIZE 4,.7
2260     MOVE X1(C2),Y2(C2)/2
2270     LABEL Y$       ! PLOTS Y-AXIS LABEL
2280  LORG 4
2290  LDIR 0
2300     MOVE X2(C2)/2,Y1(C2)
2310     LABEL X$       ! PLOTS X-AXIS LABEL
2320  !
2330  PRINT ""
2340  PRINT ""
2350  PRINT ""
2360  PRINT ""
2370  PRINT "        IS THE PLOT (AXES AND LABELS) OK?"
2380  PRINT ""
```

```
2390  PRINT "              NOTE:  IF YOU ANSWER YES OR Y"
2400  PRINT "                     PLOT WILL BE SENT TO"
2410  PRINT "                     EXTERNAL PLOTTER"
2420  INPUT F$
2430  IF F$="N" OR F$="NO" THEN GOSUB Setup_plotter  ! REDO PLOTTER SETUP
2440  !
2450  GCLEAR       ! CLEARS PLOT FROM CRT
2460  !
2470  GOSUB Ext_plotter
2480  !
2490  PENUP
2500  MOVE 0,0
2510  !
2520  GOSUB Plot_data
2530  !
2540  RETURN
2550  !
2560  !*******************************************
2570  !
2580 Ext_plotter:    ! DUMPS PLOTTER SETUP ON EXTERNAL HP-7225B PLOTTER
2590  PLOTTER IS 705,"HPGL"
2600  VIEWPORT 13,100*RATIO,10,90
2610  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
2620  IF G$="N" OR G$="NO" THEN 2730
2630  FOR I=X4/B0+X1(C2) TO X2(C2) STEP X4/B0
2640     MOVE I,Y1(C2)
2650     DRAW I,Y2(C2)
2660  NEXT I
2670  FOR I=Y4/B0+Y1(C2) TO Y2(C2) STEP Y4/B0
2680     MOVE X1(C2),I
2690     DRAW X2(C2),I
2700  NEXT I
2710  GOTO 2760
2720  IF G$="Y" OR G$="YES" THEN 2760
2730  MOVE X2(C2),Y1(C2)
2740  DRAW X2(C2),Y2(C2)
2750  DRAW X1(C2),Y2(C2)
2760  CLIP ON
2770  AXES X4,Y4,X1(C2),Y1(C2)
2780  CLIP OFF
2790  VIEWPORT 13,100*RATIO,5,90
2800  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
2810  LORG 4
2820  CSIZE 3,.6
2830  FOR X=X1(C2) TO X2(C2) STEP X4
2840     CLIP OFF
2850     MOVE X,Y1(C2)
2860     LABEL USING "K";X
2870  NEXT X
2880  VIEWPORT 4,100*RATIO,10,90
2890  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
2900  LORG 2
2910  FOR Y=Y1(C2) TO Y2(C2) STEP Y4
2920     CLIP OFF
2930     MOVE X1(C2),Y
2940     LABEL USING "K";Y
2950  NEXT Y
2960  VIEWPORT 0,100*RATIO,0,100
2970  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
2980  LORG 2
```

```
2990  CSIZE 5
3000  LORG 6
3010     MOVE X2(C2)/2,Y2(C2)
3020     LABEL T$
3030  DEG
3040  LDIR 90
3050  CSIZE 4,.7
3060     MOVE X1(C2).Y2(C2)/2
3070     LABEL Y$
3080  LORG 4
3090  LDIR 0
3100     MOVE X2(C2)/2,Y1(C2)
3110     LABEL X$
3120  !
3130  PENUP
3140  MOVE 0,0
3150  !
3160  RETURN
3170  !
3180  !*******************************************
3190  !
3200 Plot_data:        ! PLOTS TO DATA SELECTED
3210  !
3220  VIEWPORT 13.100*RATIO,10.90
3230  WINDOW X1(C2),X2(C2),Y1(C2),Y2(C2)
3240  !
3250  IF C2=1 THEN 3290
3260  IF C2=2 THEN 3340
3270  IF C2=3 THEN 3390
3280  !
3290  FOR I=1 TO K
3300     PLOT Cod(I),Lod(I)
3310  NEXT I
3320  GOTO 3430
3330  !
3340  FOR I=1 TO K
3350     PLOT Defl(I),Lod(I)
3360  NEXT I
3370  GOTO 3430
3380  !
3390  FOR I=1 TO C1
3400     PLOT Delta_a(K2),J(K2)
3410  NEXT I
3420  !
3430  PENUP
3440  BEEP
3450  RETURN        ! RETURNS TO SETUP_PLOTTER
3460  !
3470  !*******************************************
3480  !
3490  END
```

APPENDIX G

PRECRACK OUTPUT

```
USING ENGLISH UNITS (in.lbs.psi) THE FOLLOWING INFORMATION
HAS BEEN ENTERED FOR: HY80-5B

WIDTH = .9469          NOTCH LENGTH = .444
Bmax = .496        Bmin = .394
HALF SPAN = 1.894  POISSON'S RATIO = .3
YIELD STRENGTH = 86600  ULTIMATE TS = 100000
ELASTIC MODULUS = 2.9E+7  FLOW STRESS = 93300

CONVERTING THIS DATA TO METRIC UNITS (mm.N.KPa) FOR: HY80-5B
WIDTH = 24.05126        NOTCH LENGTH = 11.2776
Bmax = 12.5984      Bmin = 10.0076
YIELD STRENGTH = 597085.603738   ULTIMATE TS = 689475.293
ELASTIC MODULUS = 1.9994783497E+8   FLOW STRESS = 643280.448369

BASED ON CURRENT INFORMATION FOR HY80-5B:

CURRENT CRACK LENGTH = .444 in
OPTIMUN CRACK LENGTH = .56814 in
EXTENSION REQUIRED = .12414 in
CRACK LENGTH AT 50% OF EXTENSION = .50607 in
Pmax = 3272.42651647 Lbs  Pmin = 163.621325823 Lbs
Delp = 3108.80519064 Lbs  Kmax = 82563.7466931
DELTA_K = 78435.5593585 in^.5  DELTA_KE = 40000 in^.5

NEW LOADS  BASED ON DELTA_KE ARE:
Pmax = 1668.84843723 Lbs  Pmin = 83.4424218615 Lbs
DELTA_P = 1585.40601537 Lbs   Kmax = 42105.2631579


        CONVERSION DATA
FOR LOAD:-1779.288646 N/V   (-400 Lbs/V)
FOR COD: .0508 mm/V   ( .002 in/V)
FOR DEFLECTION:-12.7 mm/V   (-.5 in/V)
U = .07
a/W = .732186117982 in  CRACK LENGTH = .693307035117 in
LOAD (lbs)      COD (in)          COD (Volts)
 200        .00256290169302      1.28145084651
 300        .00384435253953      1.92217626976
 400        .00512580338604      2.56290169302
 500        .00640725423255      3.20362711627
 600        .00768870507906      3.84435253953
 700        .00897015592557      4.48507796278
 800        .0102516067721       5.12580338604
 900        .0115330576186       5.76652880929
 1000       .0128145084651       6.40725423255
 1100       .0140959593116       7.0479796558
 1200       .0153774101581       7.68870507906
 1300       .0166588610046       8.32943050231
 1400       .0179403118511       8.97015592557
 1500       .0192217626976       9.61088134882
 1600       .0205032135441       10.2516067721
 1700       .0217846643907       10.8923321953
 1800       .0230661152372       11.5330576186
U = .075
a/W = .713968763392 in  CRACK LENGTH = .676057022056 in
LOAD (lbs)      COD (in)          COD (Volts)
 200        .00220863052208      1.10431526104
 300        .00331294578312      1.65647289156
 400        .00441726104416      2.20863052208
 500        .00552157630521      2.7607881526
  ∫               ∫                  ∫
```

```
USING ENGLISH UNITS (in.lbs.psi) THE FOLLOWING INFORMATION
HAS BEEN ENTERED FOR: HY80-5B

WIDTH = .9469          NOTCH LENGTH = .444
Bmax = .496         Bmin = .394
HALF SPAN = 1.394  POISSON'S RATIO = .3
YIELD STRENGTH = 86600  ULTIMATE TS = 100000
ELASTIC MODULUS = 2.9E+7  FLOW STRESS = 93300

CONVERTING THIS DATA TO METRIC UNITS (mm.N.KPa) FOR: HY80-5B
WIDTH = 24.05126         NOTCH LENGTH = 11.2776
Bmax = 12.5984       Bmin = 10.0076
YIELD STRENGTH = 597085.603738   ULTIMATE TS = 689475.293
ELASTIC MODULUS = 1.9994783497E+8   FLOW STRESS = 643280.448369

BASED ON CURRENT INFORMATION FOR HY80-5B:

CURRENT CRACK LENGTH = .444 in
OPTIMUN CRACK LENGTH = .56814 in
EXTENSION REQUIRED = .12414 in
CRACK LENGTH AT 50% OF EXTENSION = .50607 in
Pmax = 3272.42651647 Lbs  Pmin = 163.621325823 Lbs
Delp = 3108.80519064 Lbs  Kmax = 82563.7466931
DELTA_K = 78435.5593585 in^.5  DELTA_KE = 40000 in^.5

NEW LOADS  BASED ON DELTA_KE ARE:
Pmax = 1668.84843723 Lbs  Pmin = 83.4424218615 Lbs
DELTA_P = 1585.40601537 Lbs   Kmax = 42105.2631579


       CONVERSION DATA
FOR LOAD:-1779.288646 N/V   (-400 Lbs/V)
FOR COD: .0508 mm/V   ( .002 in/V)
FOR DEFLECTION:-12.7 mm/V   (-.5 in/V)

THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .477215195165 in FROM MEASUREMENT # 1
WITH 95%CONFIDENCE INTERVAL FROM .47792545433  TO .476507410981 in
USING COD COMPLIANCE OF: 2.84104311054E-6 in/Lb = 1.62905173472E-5 mm/N
WITH A CORRELATION OF: .999771386472 FROM 106  DATA POINTS.


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .477198279382 in FROM MEASUREMENT # 2
WITH 95%CONFIDENCE INTERVAL FROM .478064054454  TO .476336178981 in
USING COD COMPLIANCE OF: 2.84076126094E-6 in/Lb = 1.63037750213E-5 mm/N
WITH A CORRELATION OF: .99959257929 FROM 124  DATA POINTS.

BASED ON CURRENT INFORMATION FOR HY80-5B:

CURRENT CRACK LENGTH = .477198279382 in
OPTIMUN CRACK LENGTH = .56814 in
EXTENSION REQUIRED = .0909417206182 in
CRACK LENGTH AT 50% OF EXTENSION = .489470860309 in
Pmax = 2854.63728597 Lbs  Pmin = 142.731864298 Lbs
Delp = 2711.90542167 Lbs  Kmax = 80310.2753096
DELTA_K = 76294.7615441 in^.5  DELTA_KE = 40000 in^.5

NEW LOADS  BASED ON DELTA_KE ARE:
Pmax = 1496.63606161 Lbs  Pmin = 74.8318030804 Lbs
DELTA P = 1421.80425853 Lbs   Kmax = 42105.2631579
```

```
THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .499315101398 in FROM MEASUREMENT # 1
WITH 95%CONFIDENCE INTERVAL FROM .500434044632  TO .498202259284 in
USING COD COMPLIANCE OF: 3.23884557474E-6 in/Lb = 1.86189031428E-5 mm/N
WITH A CORRELATION OF: .999477933275 FROM 94  DATA POINTS.


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .499773214641 in FROM MEASUREMENT # 2
WITH 95%CONFIDENCE INTERVAL FROM .50177796077  TO .497787999797 in
USING COD COMPLIANCE OF: 3.24775972936E-6 in/Lb = 1.8769892409E-5 mm/N
WITH A CORRELATION OF: .999019979378 FROM 57  DATA POINTS.

BASED ON CURRENT INFORMATION FOR HY80-5B:

CURRENT CRACK LENGTH = .499773214641 in
OPTIMUN CRACK LENGTH = .56814 in
EXTENSION REQUIRED = .0683667853593 in
CRACK LENGTH AT 50% OF EXTENSION = .47818339268 in
Pmax = 1034.73227996 Lbs  Pmin = 51.736613998 Lbs
Delp = 982.995665963 Lbs  Kmax = 31462.7523142
DELTA_K = 29889.6146985 in^.5  DELTA_KE = 29000 in^.5

NEW LOADS  BASED ON DELTA_KE ARE:
Pmax = 1003.9351936 Lbs  Pmin = 50.1967596798 Lbs
DELTA_P = 953.738433917 Lbs   Kmax = 30526.3157895


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .523238325069 in FROM MEASUREMENT # 1
WITH 95%CONFIDENCE INTERVAL FROM .524952826657  TO .521538109085 in
USING COD COMPLIANCE OF: 3.74604099481E-6 in/Lb = 2.16181567648E-5 mm/N
WITH A CORRELATION OF: .999183456903 FROM 61  DATA POINTS.


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .519260644793 in FROM MEASUREMENT # 2
```

```
WITH 95%CONFIDENCE INTERVAL FROM .521257634776  TO .51728301025 in
USING COD COMPLIANCE OF: 3.65545467572E-5 in/Lb = 2.11309694446E-5 mm/N
WITH A CORRELATION OF: .998905179767 FROM 61  DATA POINTS.


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .520164834896 in FROM MEASUREMENT # 3
WITH 95%CONFIDENCE INTERVAL FROM .521732160051  TO .51860945694 in
USING COD COMPLIANCE OF: 3.67581279234E-6 in/Lb = 2.11927866299E-5 mm/N
WITH A CORRELATION OF: .999107091656 FROM 79  DATA POINTS.

BASED ON CURRENT INFORMATION FOR HY80-5B:

CURRENT CRACK LENGTH = .520164834896 in
OPTIMUN CRACK LENGTH = .56814 in
EXTENSION REQUIRED = .0479751651041 in
CRACK LENGTH AT 50% OF EXTENSION = .467987582552 in
Pmax = 942.504620395 Lbs  Pmin = 47.1252310197 Lbs
Delp = 895.379389375 Lbs  Kmax = 30831.6649108
DELTA_K = 29290.0816653 in^.5  DELTA_KE = 29000 in^.5

NEW LOADS  BASED ON DELTA_KE ARE:
Pmax = 933.170289649 Lbs  Pmin = 46.6585144825 Lbs
DELTA_P = 886.511775167 Lbs   Kmax = 30526.3157895


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .557542180253 in FROM MEASUREMENT # 1
WITH 95%CONFIDENCE INTERVAL FROM .559342565208  TO .555757596687 in
USING COD COMPLIANCE OF: 4.6522934609E-6 in/Lb = 2.6877228564E-5 mm/N
WITH A CORRELATION OF: .999026349545 FROM 60  DATA POINTS.


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .556985314799 in FROM MEASUREMENT # 2
WITH 95%CONFIDENCE INTERVAL FROM .559603140017  TO .554400760935 in
USING COD COMPLIANCE OF: 4.63555555373E-6 in/Lb = 2.69227537518E-5 mm/N
WITH A CORRELATION OF: .998286279816 FROM 51  DATA POINTS.


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .55746232304 in FROM MEASUREMENT # 3
WITH 95%CONFIDENCE INTERVAL FROM .558944733365  TO .555990641885 in
USING COD COMPLIANCE OF: 4.64988856512E-6 in/Lb = 2.68079074153E-5 mm/N
WITH A CORRELATION OF: .999219985095 FROM 70  DATA POINTS.

BASED ON CURRENT INFORMATION FOR HY80-5B:

CURRENT CRACK LENGTH = .55746232304 in
OPTIMUN CRACK LENGTH = .56814 in
EXTENSION REQUIRED = .0106776769602 in
CRACK LENGTH AT 50% OF EXTENSION = .44933883848 in
Pmax = 784.95101444 Lbs  Pmin = 39.247550722 Lbs
Delp = 745.703463718 Lbs  Kmax = 29594.1425953
DELTA_K = 28114.4354655 in^.5  DELTA_KE = 29000 in^.5

THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .556873246958 in FROM MEASUREMENT # 1
WITH 95%CONFIDENCE INTERVAL FROM .558630143876  TO .555131398279 in
USING COD COMPLIANCE OF: 4.63219612139E-6 in/Lb = 2.67532481877E-5 mm/N
```

```
WITH A CORRELATION OF: .999174171419 FROM 54  DATA POINTS.

BASED ON CURRENT INFORMATION FOR HY80-5B:

CURRENT CRACK LENGTH = .556873246958 in
OPTIMUN CRACK LENGTH = .56814 in
EXTENSION REQUIRED = .0112667530417 in
CRACK LENGTH AT 50% OF EXTENSION = .449633376521 in
Pmax = 787.327495262 Lbs  Pmin = 39.3663747631 Lbs
Delp = 747.961120499 Lbs  Kmax = 29614.5302835
DELTA_K = 28133.8037694 in^.5  DELTA_KE = 29000 in^.5

THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .560000734225 in FROM MEASUREMENT # 1
WITH 95%CONFIDENCE INTERVAL FROM .56106984425  TO .55893721925 in
USING COD COMPLIANCE OF: 4.72709402318E-6 in/Lb = 2.71807983847E-5 mm/N
WITH A CORRELATION OF: .99939646638 FROM 101  DATA POINTS.


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .562208107534 in FROM MEASUREMENT # 2
WITH 95%CONFIDENCE INTERVAL FROM .56343540602  TO .560988180658 in
USING COD COMPLIANCE OF: 4.79552996551E-6 in/Lb = 2.76035025025E-5 mm/N
WITH A CORRELATION OF: .99948124671 FROM 67  DATA POINTS.

BASED ON CURRENT INFORMATION FOR HY80-5B:

CURRENT CRACK LENGTH = .562208107534 in
OPTIMUN CRACK LENGTH = .56814 in
EXTENSION REQUIRED = .00593189246594 in
CRACK LENGTH AT 50% OF EXTENSION = .446965946233 in
Pmax = 765.936366326 Lbs  Pmin = 38.2968183163 Lbs
Delp = 727.63954801 Lbs  Kmax = 29428.399829
DELTA_K = 27957.4548376 in^.5  DELTA_KE = 29000 in^.5

THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .564151471472 in FROM MEASUREMENT # 1
WITH 95%CONFIDENCE INTERVAL FROM .565674835605  TO .562639453926 in
USING COD COMPLIANCE OF: 4.85680462792E-6 in/Lb = 2.80112437379E-5 mm/N
WITH A CORRELATION OF: .999133273453 FROM 72  DATA POINTS.


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
CRACK LENGTH = .568361917225 in FROM MEASUREMENT # 2
WITH 95%CONFIDENCE INTERVAL FROM .569305393318  TO .567422811142 in
USING COD COMPLIANCE OF: 4.99294827909E-6 in/Lb = 2.86883916896E-5 mm/N
WITH A CORRELATION OF: .999601697254 FROM 84  DATA POINTS.

      PRECRACKING IS COMPLETED!

FINAL CRACK LENGTH = .568361917225
CORRELATION OF DATA = .999601697254

     REMOVE SPECIMEN FROM MTS.
```

APPENDIX H

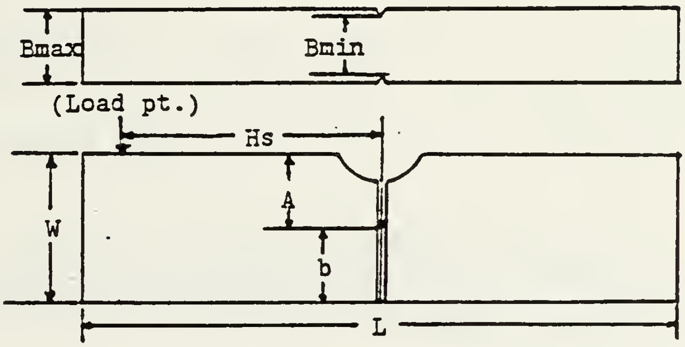
J_INTGL OUTPUT

THREE POINT BEND SPECIMEN

TEST REPORT

SPECIMEN I.D. HY80-5B MATERIAL HY80 ORIENTATION T-S

Date 12/13/83 Operator TRITCHLER Test Temp 21C



W = 0.9469" A = 0.444" b = 0.5029" L = 4.5"

Hs = 1.894" Bmax = 0.4960" Bmin = 0.394"

Ys = 86600 psi Uts = 100000 psi Fs = 93300 psi

Poisson's ratio = 0.3 Elastic Modulus = 2.9×10^7 psi

Comments:

HY80 BASE METAL FROM PREHEATED WELD

PRECRACKED ON 12/11/83; J-TEST ON 12/13/83 ⇒ $J_{Ic} = 142$ KJ/m^2

```
USING ENGLISH UNITS (in.lbs.psi) THE FOLLOWING INFORMATION
HAS BEEN ENTERED FOR: HY80-5B

WIDTH = .9469        NOTCH LENGTH = .444
Bmax = .496       Bmin = .394
HALF SPAN = 1.894  POISSON'S RATIO = .3
YIELD STRENGTH = 86600  ULTIMATE TS = 100000
ELASTIC MODULUS = 2.9E+7  FLOW STRESS = 93300

CONVERTING THIS DATA TO METRIC UNITS (mm.N.KPa) FOR: HY80-5B
WIDTH = 24.05126         NOTCH LENGTH = 11.2776
Bmax = 12.5984      Bmin = 10.0076
HALF SPAN = 48.1076      POISSON'S RATIO = .3
YIELD STRENGTH = 597085.603738   ULTIMATE TS = 689475.293
ELASTIC MODULUS = 1.9994783497E+8   FLOW STRESS = 643280.448369


       CONVERSION DATA
FOR LOAD:-1779.288646 N/V   ( 400 Lbs/V)
FOR COD: .254 mm/V   ( .01 in/V)
FOR DEFLECTION:-1.27 mm/V   ( .05 in/V)

GIVEN a= .568 inches THEN:
   Pmax= 895.290182804 Lbs FROM ASTM E813-81


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
INITIAL CRACK LENGTH = 14.3875382557 mm FROM MEASUREMENT # 1
WITH 95% CONFIDENCE INTERVAL FROM 14.4079726404  TO 14.3671845862 mm
USING COD COMPLIANCE OF: 2.81520064535E-5 mm/N
WITH A CORRELATION OF: .999323843963 FROM 189 DATA POINTS.


THE FOLLOWING INFORMATION HAS BEEN OBTAINED:
INITIAL CRACK LENGTH = 14.4326755548 mm FROM MEASUREMENT # 2
WITH 95% CONFIDENCE INTERVAL FROM 14.4442813846  TO 14.42109582 mm
USING COD COMPLIANCE OF: 2.84829954475E-5 mm/N
WITH A CORRELATION OF: .99984474937 FROM 134 DATA POINTS.
```

```
INITIAL CRACK LENGTH = 14.4455712237 mm FROM MEASUREMENT # 3
WITH 95% CONFIDENCE INTERVAL FROM 14.4565506791  TO 14.434615129 mm
USING COD COMPLIANCE OF: 2.85784514764E-5 mm/N
WITH A CORRELATION OF: .999816522357 FROM 176 DATA POINTS.


      ----  UNLOADING # 1  ----

CRACK LENGTH = 14.4487507815 mm    DELTA _a = .016075226716 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 14.4693514291  TO 14.4282322251

TOTAL # DATA POINTS = 632    # DATA POINTS THIS UNLOADING = 128
CORRELATION = .999529434569
COD COMPLIANCE = 2.87555293817E-5 mm/N

AREA = 711.365042717 N*mm
J = 14.8049806501 KJ/m^2
MAX LOAD LINE DEFLECTION = .24034834255 mm
CHANGE IN COD = .00109982 mm


      ----  UNLOADING # 2  ----

CRACK LENGTH = 14.4711513219 mm    DELTA _a = .0384757670308 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 14.4927078135  TO 14.4496847244

TOTAL # DATA POINTS = 947    # DATA POINTS THIS UNLOADING = 132
CORRELATION = .999467111958
COD COMPLIANCE = 2.89307913363E-5 mm/N

AREA = 1693.69098454 N*mm
J = 35.2970225265 KJ/m^2
MAX LOAD LINE DEFLECTION = .382347556072 mm
CHANGE IN COD = .0008382 mm


      ----  UNLOADING # 3  ----

CRACK LENGTH = 14.4875164202 mm    DELTA _a = .0548408654168 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 14.5143346851  TO 14.460837178

TOTAL # DATA POINTS = 1300    # DATA POINTS THIS UNLOADING = 157
CORRELATION = .999017363069
COD COMPLIANCE = 2.90942709989E-5 mm/N

AREA = 3033.0003923 N*mm
J = 63.28381022 KJ/m^2
MAX LOAD LINE DEFLECTION = .543433314464 mm
CHANGE IN COD = .0009398 mm


      ----  UNLOADING # 4  ----

CRACK LENGTH = 14.5414951598 mm    DELTA _a = .108819604992 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 14.5601316376  TO 14.5229259715

TOTAL # DATA POINTS = 1670    # DATA POINTS THIS UNLOADING = 109
CORRELATION = .999675611283
COD COMPLIANCE = 2.94442988118E-5 mm/N

AREA = 5208.32927275 N*mm
J = 108.998439815 KJ/m^2
MAX LOAD LINE DEFLECTION = .782918890293 mm
```

```
CHANGE IN COD = .0007874 mm

      ----  UNLOADING # 5  ----

CRACK LENGTH = 14.7407494376 mm    DELTA _a = .308073862773 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 14.7587196422  TO 14.7228419911

TOTAL # DATA POINTS = 2060     # DATA POINTS THIS UNLOADING = 95
CORRELATION = .999731105207
COD COMPLIANCE = 3.10248861726E-5 mm/N

AREA = 8216.7400787 N*mm
J = 169.858689852 KJ/m^2
MAX LOAD LINE DEFLECTION = 1.10455056629 mm
CHANGE IN COD = .0008636 mm

      ----  UNLOADING # 6  ----

CRACK LENGTH = 14.8152586049 mm    DELTA _a = .382583050059 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 14.8481840789  TO 14.782543466

TOTAL # DATA POINTS = 2280     # DATA POINTS THIS UNLOADING = 138
CORRELATION = .998642018089
COD COMPLIANCE = 3.17719219461E-5 mm/N

AREA = 9001.97373669 N*mm
J = 185.342172083 KJ/m^2
MAX LOAD LINE DEFLECTION = 1.18989063161 mm
CHANGE IN COD = .0009906 mm

      ----  UNLOADING # 7  ----

CRACK LENGTH = 14.8695206824 mm    DELTA _a = .436845127588 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 14.8849566722  TO 14.8541311238

TOTAL # DATA POINTS = 2531     # DATA POINTS THIS UNLOADING = 147
CORRELATION = .999677856393
COD COMPLIANCE = 3.20855798284E-5 mm/N

AREA = 9678.11102926 N*mm
J = 198.876552682 KJ/m^2
MAX LOAD LINE DEFLECTION = 1.26297067275 mm
CHANGE IN COD = .0004572 mm

      ----  UNLOADING # 8  ----

CRACK LENGTH = 15.0148445285 mm    DELTA _a = .582168973634 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 15.0416778385  TO 14.9881516089

TOTAL # DATA POINTS = 2761     # DATA POINTS THIS UNLOADING = 97
CORRELATION = .999364204197
COD COMPLIANCE = 3.34673392487E-5 mm/N

AREA = 10586.6765231 N*mm
J = 215.448776655 KJ/m^2
MAX LOAD LINE DEFLECTION = 1.36396114491 mm
```

```
CHANGE IN COD = .0006604 mm


      ----  UNLOADING # 9  ----

CRACK LENGTH = 15.1216765395 mm    DELTA _a = .689000984704 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 15.1358606171  TO 15.1075318754

TOTAL # DATA POINTS = 3042    # DATA POINTS THIS UNLOADING = 119
CORRELATION = .99977636544
COD COMPLIANCE = 3.43343078736E-5 mm/N

AREA = 11709.4655627 N*mm
J = 237.699077286 KJ/m^2
MAX LOAD LINE DEFLECTION = 1.49020183752 mm
CHANGE IN COD = .0005842 mm


      ----  UNLOADING # 10  ----

CRACK LENGTH = 15.2624877891 mm    DELTA _a = .829812234314 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 15.2760292626  TO 15.2489823604

TOTAL # DATA POINTS = 3394    # DATA POINTS THIS UNLOADING = 167
CORRELATION = .999700915055
COD COMPLIANCE = 3.56785340653E-5 mm/N

AREA = 12983.4083914 N*mm
J = 262.394826944 KJ/m^2
MAX LOAD LINE DEFLECTION = 1.63760345064 mm
CHANGE IN COD = .0007366 mm


      ----  UNLOADING # 11  ----

CRACK LENGTH = 15.3993548961 mm    DELTA _a = .966679341294 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 15.4107739959  TO 15.3879615278

TOTAL # DATA POINTS = 3867    # DATA POINTS THIS UNLOADING = 204
CORRELATION = .999734089719
COD COMPLIANCE = 3.70351235759E-5 mm/N

AREA = 14557.9277896 N*mm
J = 294.038000741 KJ/m^2
MAX LOAD LINE DEFLECTION = 1.82262379631 mm
CHANGE IN COD = .0004318 mm


      ----  UNLOADING # 12  ----

CRACK LENGTH = 15.669999544 mm    DELTA _a = 1.2373239892 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 15.6847004127  TO 15.6553416287

TOTAL # DATA POINTS = 4267    # DATA POINTS THIS UNLOADING = 154
CORRELATION = .999652892868
COD COMPLIANCE = 4.00050024785E-5 mm/N

AREA = 16330.4160222 N*mm
J = 325.442585526 KJ/m^2
MAX LOAD LINE DEFLECTION = 2.03825076401 mm
```

```
CHANGE IN COD = .0013462 mm


      ----  UNLOADING # 13  ----

CRACK LENGTH = 15.8781418346 mm    DELTA _a = 1.44546627973 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 15.8901071812  TO 15.8662051558

TOTAL # DATA POINTS = 4710     # DATA POINTS THIS UNLOADING = 208
CORRELATION = .999677232181
COD COMPLIANCE = 4.24377123766E-5 mm/N

AREA = 17933.7183158 N*mm
J = 355.360006494 KJ/m^2
MAX LOAD LINE DEFLECTION = 2.24213294335 mm
CHANGE IN COD = .000508 mm


      ----  UNLOADING # 14  ----

CRACK LENGTH = 16.1357477216 mm    DELTA _a = 1.7030721668 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 16.1463233402  TO 16.1251947229

TOTAL # DATA POINTS = 5206     # DATA POINTS THIS UNLOADING = 239
CORRELATION = .999696024845
COD COMPLIANCE = 4.57508725867E-5 mm/N

AREA = 19646.0705407 N*mm
J = 385.620902249 KJ/m^2
MAX LOAD LINE DEFLECTION = 2.47449867471 mm
CHANGE IN COD = .0004826 mm


      ----  UNLOADING # 15  ----

CRACK LENGTH = 16.4193583405 mm    DELTA _a = 1.98668278568 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 16.4364102869  TO 16.4023658462

TOTAL # DATA POINTS = 5648     # DATA POINTS THIS UNLOADING = 194
CORRELATION = .999324290353
COD COMPLIANCE = 4.99261698493E-5 mm/N

AREA = 21264.009056 N*mm
J = 412.083508069 KJ/m^2
MAX LOAD LINE DEFLECTION = 2.70365472703 mm
CHANGE IN COD = .0005334 mm


      ----  UNLOADING # 16  ----

CRACK LENGTH = 16.9028626935 mm    DELTA _a = 2.47018713865 mm
95% CONFIDENCE INTERVAL ON CRACK LENGTH IS FROM 16.9171113874  TO 16.888656585

TOTAL # DATA POINTS = 6102     # DATA POINTS THIS UNLOADING = 162
CORRELATION = .999564028818
COD COMPLIANCE = 5.80350094828E-5 mm/N

AREA = 22950.1834392 N*mm
J = 428.162914109 KJ/m^2
MAX LOAD LINE DEFLECTION = 2.96684800605 mm
```

```
DATA FROM J vs DELTA_a PLOT

SLOPE = 164.148013927     Y-INTERCEPT = 123.933075018
CORRELATION = .99667195294   FROM 9  DATA POINTS.

      J1c = 142.05774949


 TEST IS OVER!
UNLOADING #     DELTA_a(mm)     J(KJ/m^2)
        1       .016075          14.8
        2       .038476          35.3
        3       .054841          63.3
        4       .108820         109.0
        5       .308074         169.9
        6       .382583         185.3
        7       .436845         198:9
        8       .582169         215.4
        9       .689001         237.7
       10       .829812         262.4
       11       .966679         294.0
       12      1.237324         325.4
       13      1.445466         355.4
       14      1.703072         385.6
       15      1.986683         412.1
       16      2.470187         428.2
```

```
DATA FROM J vs DELTA_a PLOT

SLOPE = 164.148013927     Y-INTERCEPT = 123.933075018
CORRELATION = .99667195294   FROM 9  DATA POINTS.

      J1c = 142.05774949


 TEST IS OVER!
```

APPENDIX I

J_DATA OUTPUT

```
WHAT DATA FILE DO YOU WISH TO READ?

J-INTEGRAL TEST OF HY80-5B   BY: KURT

DATE: 12-13-83       TIME: 10:35


a0= 14.4326755548   WITH 95% CONDIFENCE INTERVAL
FROM 14.4442813846    TO 14.42109582

FROM COMPLIANCE =  2.84829954475E-5

CORRELATION= .99984474937 FROM 176 DATA POINTS

DO YOU WANT A HARD COPY OF THIS INFORMATION?
```

```
FROM UNLOADING # 1 RECORDED 128 DATA POINTS
COD COMPLIANCE = 2.87555293817E-5 mm/N   CORRELATION = .999529434569
CRACK LENGTH = 14.4487507815 mm   DELTA_A = .016075226716 mm
95% CONFIDENCE INTERVAL FROM 14.4693514291 mm TO 14.4282322251 mm
AREA = 711.365042717 N*mm   J = 14.8049806501 KPa*m
DATA POINT INDEXES FROM 504 TO 632  WERE USED.


FROM UNLOADING # 2 RECORDED 132 DATA POINTS
COD COMPLIANCE = 2.89307913363E-5 mm/N   CORRELATION = .999467111958
CRACK LENGTH = 14.4711513219 mm   DELTA_A = .0384757670308 mm
95% CONFIDENCE INTERVAL FROM 14.4927078135 mm TO 14.4496847244 mm
AREA = 1693.69098454 N*mm   J = 35.2970225265 KPa*m
DATA POINT INDEXES FROM 815 TO 947  WERE USED.


FROM UNLOADING # 3 RECORDED 157 DATA POINTS
COD COMPLIANCE = 2.90942709989E-5 mm/N   CORRELATION = .999017363069
CRACK LENGTH = 14.4875164202 mm   DELTA_A = .0548408654168 mm
95% CONFIDENCE INTERVAL FROM 14.5143346851 mm TO 14.460837178 mm
AREA = 3033.0003923 N*mm   J = 63.28381022 KPa*m
DATA POINT INDEXES FROM 1143 TO 1300  WERE USED.


FROM UNLOADING # 4 RECORDED 109 DATA POINTS
COD COMPLIANCE = 2.94442988118E-5 mm/N   CORRELATION = .999675611283
CRACK LENGTH = 14.5414951598 mm   DELTA_A = .108819604992 mm
95% CONFIDENCE INTERVAL FROM 14.5601316376 mm TO 14.5229259715 mm
AREA = 5208.32927275 N*mm   J = 108.998439815 KPa*m
DATA POINT INDEXES FROM 1561 TO 1670  WERE USED.


FROM UNLOADING # 5 RECORDED 95 DATA POINTS
COD COMPLIANCE = 3.10248861726E-5 mm/N   CORRELATION = .999731105207
```

```
CRACK LENGTH = 14.7407494376 mm   DELTA_A = .308073882773 mm
95% CONFIDENCE INTERVAL FROM 14.7587196422 mm TO 14.7228419911 mm
AREA = 8216.7400787 N*mm   J = 169.858689852 KPa*m
DATA POINT INDEXES FROM 1965 TO 2060  WERE USED.


FROM UNLOADING # 6 RECORDED 138 DATA POINTS
COD COMPLIANCE = 3.17719219461E-5 mm/N   CORRELATION = .998642018089
CRACK LENGTH = 14.8152586049 mm   DELTA_A = .382583050059 mm
95% CONFIDENCE INTERVAL FROM 14.8481840789 mm TO 14.782543466 mm
AREA = 9001.97373669 N*mm   J = 185.342172083 KPa*m
DATA POINT INDEXES FROM 2142 TO 2280  WERE USED.


FROM UNLOADING # 7 RECORDED 147 DATA POINTS
COD COMPLIANCE = 3.20855798284E-5 mm/N   CORRELATION = .999677856393
CRACK LENGTH = 14.8695206824 mm   DELTA_A = .436845127588 mm
95% CONFIDENCE INTERVAL FROM 14.8849566722 mm TO 14.8541311238 mm
AREA = 9678.11102926 N*mm   J = 198.876552682 KPa*m
DATA POINT INDEXES FROM 2384 TO 2531  WERE USED.


FROM UNLOADING # 8 RECORDED 97 DATA POINTS
COD COMPLIANCE = 3.34673392487E-5 mm/N   CORRELATION = .999364204197
CRACK LENGTH = 15.0148445285 mm   DELTA_A = .582168973634 mm
95% CONFIDENCE INTERVAL FROM 15.0416778385 mm TO 14.9881516089 mm
AREA = 10586.6765231 N*mm   J = 215.448776655 KPa*m
DATA POINT INDEXES FROM 2664 TO 2761  WERE USED.


FROM UNLOADING # 9 RECORDED 119 DATA POINTS
COD COMPLIANCE = 3.43343078736E-5 mm/N   CORRELATION = .99977636544
CRACK LENGTH = 15.1216765395 mm   DELTA_A = .689000984704 mm
95% CONFIDENCE INTERVAL FROM 15.1358606171 mm TO 15.1075318754 mm
AREA = 11709.4655627 N*mm   J = 237.699077286 KPa*m
DATA POINT INDEXES FROM 2923 TO 3042  WERE USED.


FROM UNLOADING # 10 RECORDED 167 DATA POINTS
COD COMPLIANCE = 3.56785340653E-5 mm/N   CORRELATION = .999700915055
CRACK LENGTH = 15.2624877891 mm   DELTA_A = .829812234314 mm
95% CONFIDENCE INTERVAL FROM 15.2760292626 mm TO 15.2489823604 mm
AREA = 12983.4083914 N*mm   J = 262.394826944 KPa*m
DATA POINT INDEXES FROM 3227 TO 3394  WERE USED.


FROM UNLOADING # 11 RECORDED 204 DATA POINTS
COD COMPLIANCE = 3.70351235759E-5 mm/N   CORRELATION = .999734089719
CRACK LENGTH = 15.3993548961 mm   DELTA_A = .966679341294 mm
95% CONFIDENCE INTERVAL FROM 15.4107739959 mm TO 15.3879615278 mm
AREA = 14557.9277896 N*mm   J = 294.038000741 KPa*m
DATA POINT INDEXES FROM 3663 TO 3867  WERE USED.


FROM UNLOADING # 12 RECORDED 154 DATA POINTS
COD COMPLIANCE = 4.00050024785E-5 mm/N   CORRELATION = .999652892868
CRACK LENGTH = 15.669999544 mm   DELTA_A = 1.2373239892 mm
95% CONFIDENCE INTERVAL FROM 15.6847004127 mm TO 15.6553416287 mm
AREA = 16330.4160222 N*mm   J = 325.442585526 KPa*m
DATA POINT INDEXES FROM 4113 TO 4267  WERE USED.
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FROM UNLOADING # 13 RECORDED 208 DATA POINTS
COD COMPLIANCE = 4.24377123766E-5 mm/N   CORRELATION = .999677232131
CRACK LENGTH = 15.8781418346 mm   DELTA_A = 1.44546627973 mm
95% CONFIDENCE INTERVAL FROM 15.8901071812 mm TO 15.8662051558 mm
AREA = 17933.7183158 N*mm   J = 355.360006494 KPa*m
DATA POINT INDEXES FROM 4502 TO 4710  WERE USED.


FROM UNLOADING # 14 RECORDED 239 DATA POINTS
COD COMPLIANCE = 4.57508725867E-5 mm/N   CORRELATION = .999696024845
CRACK LENGTH = 16.1357477216 mm   DELTA_A = 1.7030721668 mm
95% CONFIDENCE INTERVAL FROM 16.1463233402 mm TO 16.1251947229 mm
AREA = 19646.0705407 N*mm   J = 385.620902249 KPa*m
DATA POINT INDEXES FROM 4967 TO 5206  WERE USED.


FROM UNLOADING # 15 RECORDED 194 DATA POINTS
COD COMPLIANCE = 4.99261698493E-5 mm/N   CORRELATION = .999324290353
CRACK LENGTH = 16.4193583405 mm   DELTA_A = 1.98668278568 mm
95% CONFIDENCE INTERVAL FROM 16.4364102869 mm TO 16.4023658462 mm
AREA = 21264.009056 N*mm   J = 412.083508069 KPa*m
DATA POINT INDEXES FROM 5454 TO 5648  WERE USED.


FROM UNLOADING # 16 RECORDED 162 DATA POINTS
COD COMPLIANCE = 5.80350094828E-5 mm/N   CORRELATION = .999564028818
CRACK LENGTH = 16.9028626935 mm   DELTA_A = 2.47018713865 mm
95% CONFIDENCE INTERVAL FROM 16.9171113874 mm TO 16.888656585 mm
AREA = 22950.1834392 N*mm   J = 428.162914109 KPa*m
DATA POINT INDEXES FROM 5940 TO 6102  WERE USED.
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DATA FROM aU FOR:HY80-5B   BY: KURT

TESTED ON: 12-13-83  TIME: 10:35

PT #      LOAD (N)      DEFLECTION (mm)     COD (mm)
     1     2262.5          .079424           .060576
     2     2261.7          .074706           .060576
     3     2265.2          .076740           .060637
     4     2277.8          .079003           .061003
     5     2350.8          .093469           .063589
     6     2409.0          .094978           .065014
     7     2442.3          .095627           .065895
     8     2463.4          .096491           .066429
     9     2478.9          .096968           .066954
    10     2496.2          .097378           .067280
    11     2505.2          .097666           .067627
    12     2515.4          .098165           .067772
    13     2526.1          .098554           .068207
    14     2539.6          .099114           .068511
    15     2554.0          .099864           .068969
    16     2570.4          .100177           .069411
    17     2595.3          .101411           .070231
    18     2624.1          .102889           .071107
    19     2658.4          .103775           .072045
    20     2688.5          .104678           .072903
    21     2722.7          .106054           .073863
    22     2746.9          .106721           .074519
    23     2764.1          .107052           .075024
    24     2779.2          .108077           .075443
    25     2799.9          .108725           .075956
    26     2820.2          .109596           .076655
    27     2837.8          .110482           .077142
    28     2854.0          .110667           .077617
    29     2873.4          .112035           .078313
    30     2939.6          .114805           .080284
    31     2984.9          .115696           .081471

    ∫        ∫                ∫                  ∫

 6085     5686.4          2.954239          2.460422
 6086     5692.7          2.954786          2.460701
 6087     5699.1          2.955204          2.461209
 6088     5704.9          2.955629          2.461616
 6089     5716.5          2.956736          2.462454
 6090     5731.8          2.957790          2.463394
 6091     5747.5          2.959093          2.464359
 6092     5761.2          2.959789          2.465172
 6093     5768.6          2.960445          2.465730
 6094     5777.0          2.961089          2.466442
 6095     5785.5          2.961730          2.467051
 6096     5792.8          2.962262          2.467534
 6097     5803.0          2.963643          2.468321
 6098     5812.6          2.964142          2.469007
 6099     5818.6          2.964692          2.469540
 6100     5824.1          2.965503          2.470175
 6101     5830.0          2.965801          2.470582
 6102     5836.8          2.966848          2.471293
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